Airborne Wind Shear Detection and Warning Systems

Second Combined Manufacturers' and Technologists' Conference

Compiled by
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Federal Aviation Administration
Washington, D.C.

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NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

U.S. Department of Transportation
Federal Aviation Administration

FOREWORD

The Second Combined Manufacturers' and Technologists' Conference was hosted jointly by NASA Langley Research Center (LaRC) and the Federal Aviation Administration (FAA) in Williamsburg, Virginia on October 18-20, 1988. The meeting was co-chaired by Dr. Roland Bowles of LaRC and Herbert Schlickenmaier of the FAA. Amos Spady of LaRC and the Science and Technology Corporation coordinated the meeting.

The purpose of the meeting was to transfer significant ongoing results gained during the second year of the NASA/FAA joint Airborne Wind Shear Program to the technical industry and to pose problems of current concern to the combined group. It also provided a forum for manufacturers to review forward-look technology concepts and for technologists to gain an understanding of the problems encountered by the manufacturers during the development of airborne equipment and the FAA certification requirements.

The present document has been compiled to record the essence of the technology updates and discussions which followed each. Updates are represented here through the unedited duplication of the vugraphs, which were generously provided by the respective speakers. When time was available questions were requested in writing. Questions and answers from the floor are included for all sessions. The written questions were presented and answered in the final session and are included in the document. Several of the speakers did not have vugraphs; their talks were transcribed from the recordings of the sessions, edited by the speaker, and are included. Additionally, the opening overview by Mr. David Johnson was transcribed and included to provide the reader with an understanding of the multiple elements included in the Joint Airborne Wind Shear Program.

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Session I. Airborne—Sensors

*Published under separate cover.

Part 2

Session II. Airborne—Flight Management

4. TECHNICAL PRESENTATIONS - Thursday, 20 October 1988

Session I. Ground Systems

Session II. Airborne—Flight Management

Session II. Airborne–Flight Management

Flight Guidance Research for Recovery from Microburst Wind Shear
David A. Hinton, NASA LaRC

N91-11696

FLIGHT GUIDANCE RESEARCH FOR RECOVERY FROM MICROBURST WIND SHEAR

David A. Hinton
NASA, Langley Research Center
Hampton, Virginia 23665

ABSTRACT

Research is in progress to develop flight strategy concepts for avoidance and recovery from microburst wind shears. The objectives of this study are to evaluate the performance of various strategies for recovery from wind shear encountered during the approach-to-landing, examine the associated piloting factors, and evaluate the payoff of forward-look sensing. Both batch and piloted simulations are utilized. The industry-recommended manual recovery technique is used as a baseline strategy. Two advanced strategies were selected for the piloted tests. The first strategy emulates the recovery characteristics shown by prior optimal trajectory analysis, by initially tracking the glideslope, then commanding a shallow climb. The second strategy generates a flight path angle schedule that is a function of airplane energy state and the instantaneous shear strength. All three strategies are tested with reactive sensing only and with forward-look sensing.

Piloted simulation tests are in progress. Tentative results indicate that, using only reactive alerts, there appears to be little difference in performance between the various strategies. With forward-look alerts, the advanced guidance strategies appear to have advantages over the baseline strategy. Relatively short forward-look alert times, on the order of 10 or 15 seconds, produce a far greater recovery benefit than optimizing a recovery from a reactive alert.

FLIGHT GUIDANCE RESEARCH FOR RECOVERY FROM MICROBURST WIND SHEAR

DAVID A. HINTON

NASA, LANGLEY RESEARCH CENTER

OCTOBER 19, 1988

THE WINDSHEAR PROBLEM
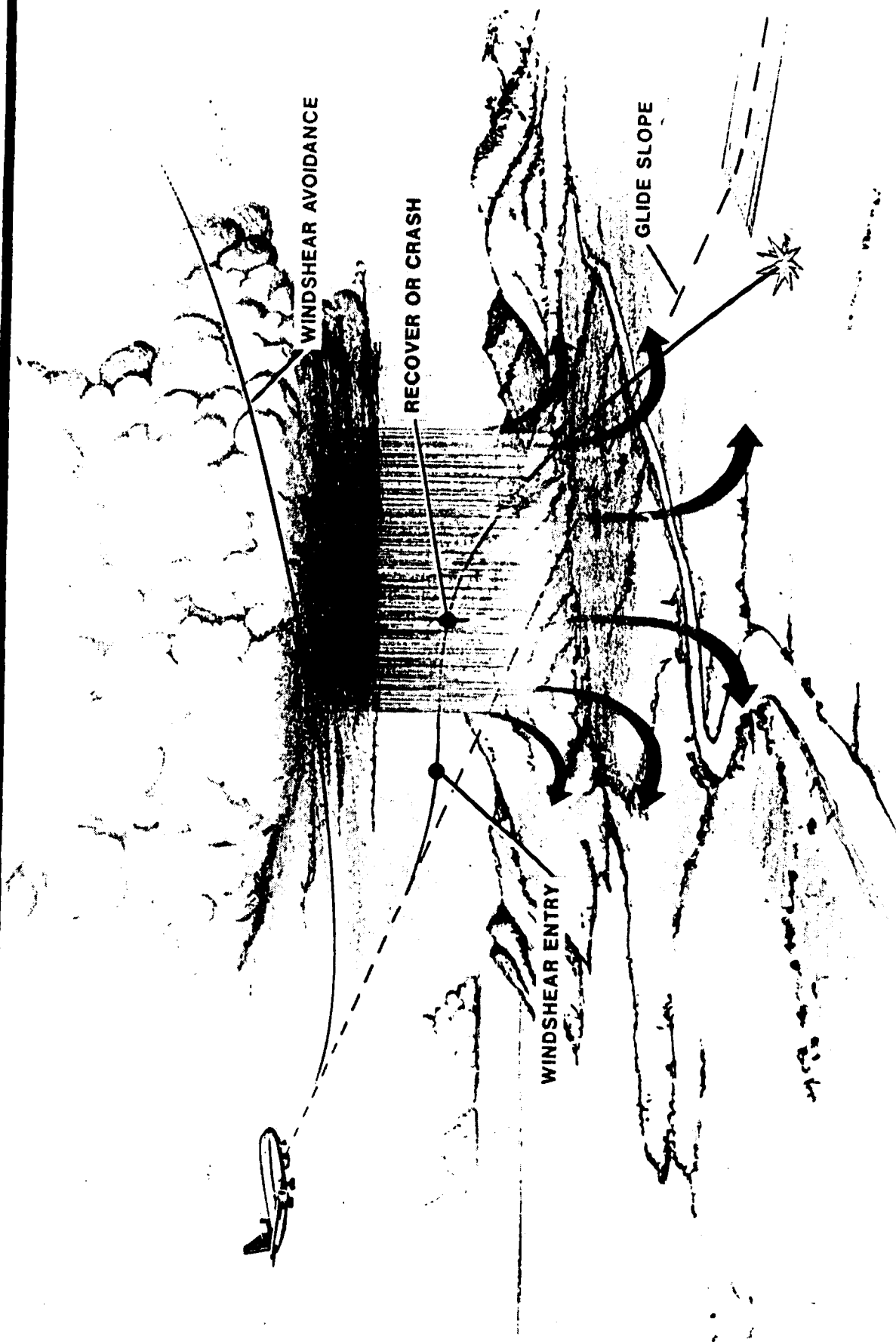
WINDSHEAR AVOIDANCE

RECOVER OR CRASH

GLIDE SLOPE

WINDSHEAR ENTRY

OUTLINE

- **SUMMARY OF PREVIOUS RESEARCH**

- **PREDICTED PAYOFF FROM FORWARD-LOOK SENSING**

- **APPROACH-TO-LANDING WIND SHEAR RECOVERY GUIDANCE**

- **CONCLUSIONS**

PREVIOUS RESEARCH

- OPTIMAL TRAJECTORY ANALYSIS, TAKEOFF AND LANDING ENCOUNTERS

- PILOTED SIMULATION OF TAKEOFF-CASE RECOVERY STRATEGIES

- SIGNIFICANT RESULTS:

  - SIGNIFICANT BENEFITS PREDICTED BY INITIALLY FLYING A LOW FLIGHT PATH ANGLE AND DELAYING STICK SHAKER ACTIVATION TILL END OF SHEAR

  - RECOVERIES HIGHLY SENSITIVE TO SMALL PERTURBATIONS

  - PERFORMANCE INCREASE OF ADVANCED STRATEGIES STATISTICALLY INSIGNIFICANT IN REAL-TIME RUNS DUE TO PILOTING FACTORS

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FORWARD-LOOK PAYOFF

- **CONSIDER CHANGE IN ENERGY HEIGHT ACROSS AN EVENT, AS A FUNCTION OF FORWARD-LOOK ALERT TIME**

- **ENERGY HEIGHT** $= \dfrac{V^2}{2g} + h$

- **RATE OF CHANGE IN ENERGY HEIGHT IS A FUNCTION OF AIRPLANE PERFORMANCE AND F-FACTOR**

$$\dot{Eh} = V\left(\frac{T-D}{w} - F\right)$$

- **ASSUMPTIONS:**

    - **CONSTANT F-FACTOR IN SHEAR**
    - **TWO THRUST VALUES, APPROACH AND GO-AROUND**
    - **2-SEC DELAY FROM ALERT TO GO-AROUND**
    - **CONSTANT AIRPLANE CONFIGURATION**

- **CAN BE COMPARED TO USEFUL ENERGY HEIGHT AT BEGINNING OF AN EVENT**

$$Eh_u = \frac{V^2}{2g} - \frac{V_{ss}^2}{2g} + h$$

SCENARIO FOR ENERGY HEIGHT ANALYSIS
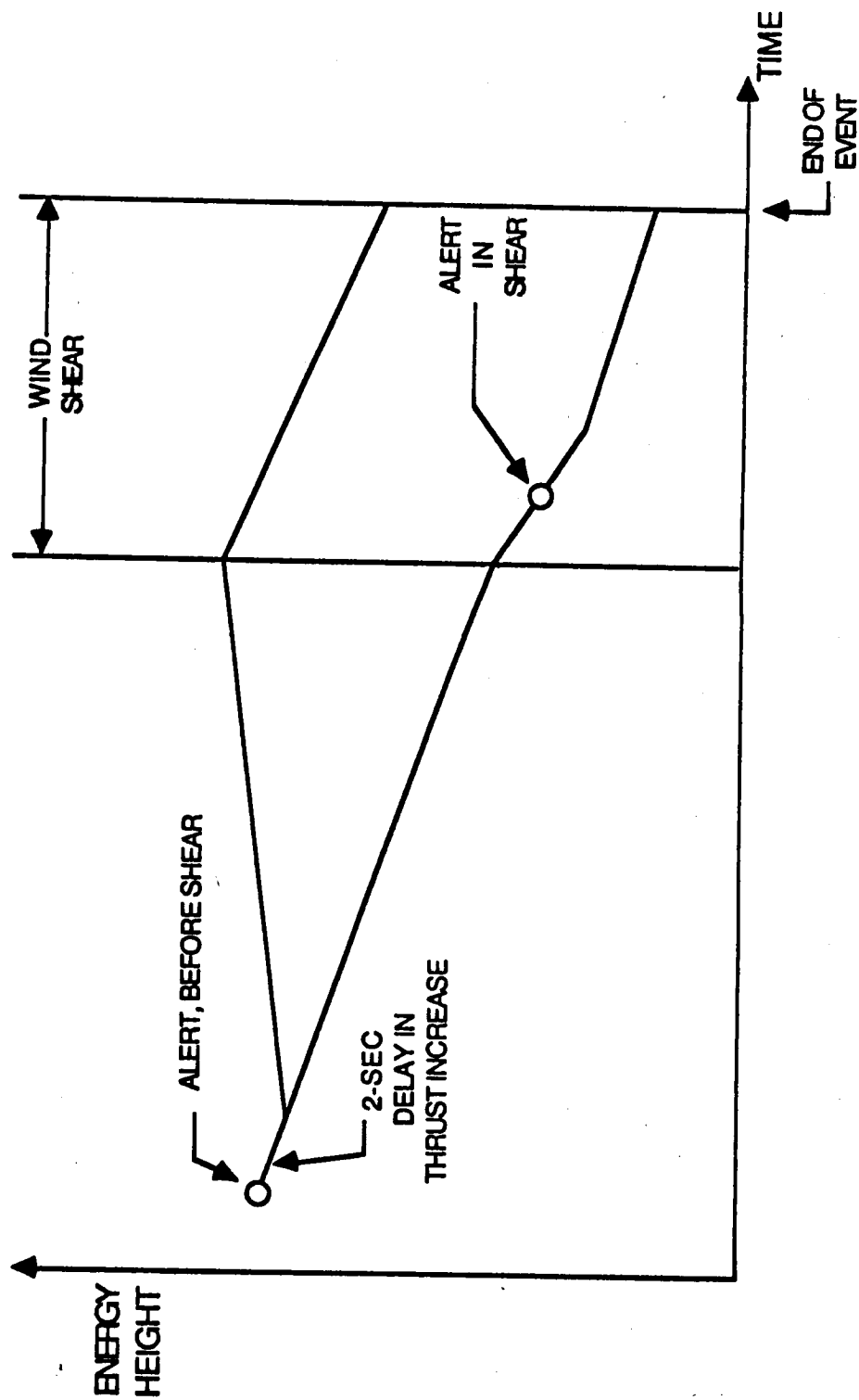
○ INTEGRATE $\dot{h}_p$ FROM ALERT (OR FROM SHEAR ENTRY IF ALERT IS GIVEN IN THE SHEAR) TO SHEAR EXIT.

CHANGE IN ENERGY HEIGHT ACROSS AN EVENT

WITH FORWARD LOOK

FORWARD LOOK ALERT TIME, sec.

DELTA ENERGY HEIGHT, ft.
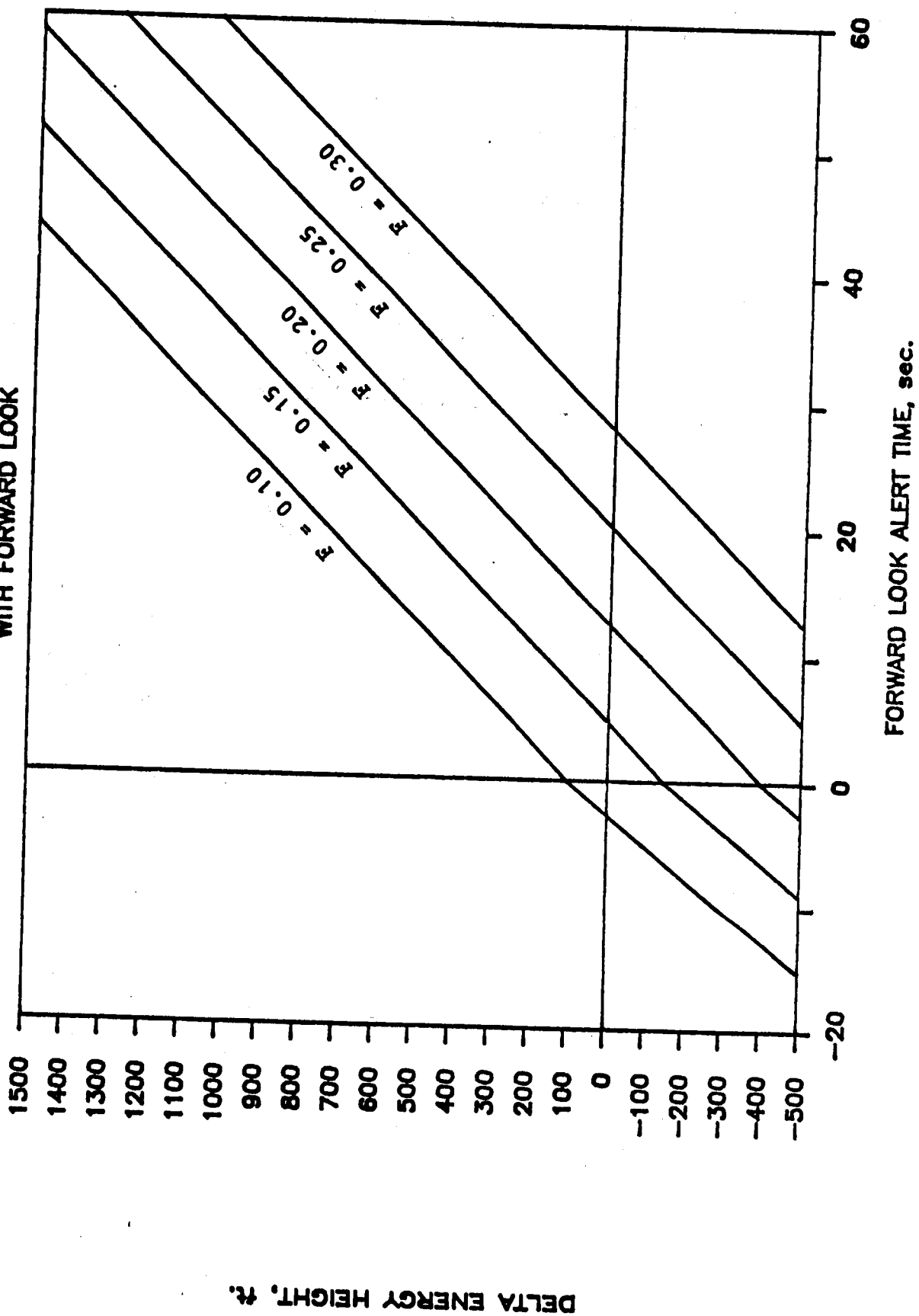
CHANGE IN ENERGY HEIGHT

COMPARISON TO PILOTED TAKEOFF RUNS
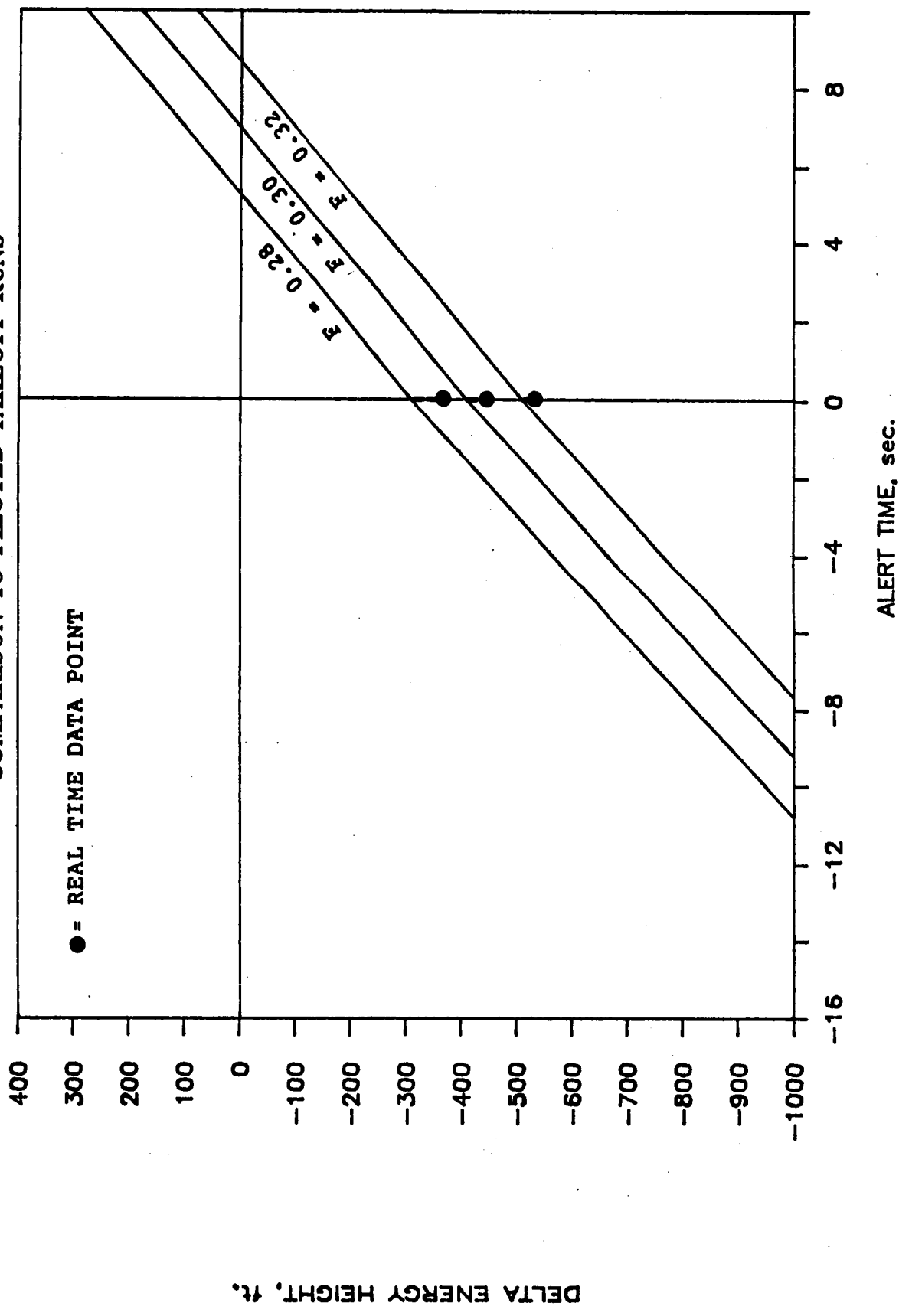
● = REAL TIME DATA POINT

$\epsilon = 0.28$

$\epsilon = 0.30$

$\epsilon = 0.32$

ALERT TIME, sec.

DELTA ENERGY HEIGHT, ft.

OUTLINE

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- ▲ **APPROACH-TO-LANDING WIND SHEAR RECOVERY GUIDANCE**

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APPROACH TO LANDING RECOVERY GUIDANCE

OBJECTIVE: DETERMINE PERFORMANCE OF CANDIDATE ADVANCED RECOVERY STRATEGIES, PILOTING FACTORS, AND FORWARD-LOOK PAYOFF IN APPROACH CASE ENCOUNTERS

APPROACH: BATCH AND PILOTED SIMULATION OF WIND SHEAR ENCOUNTERS

TOOLS:
- ADVANCED ANALYTICAL WIND SHEAR MODEL
- NUMERIC MODEL, DFW BASED
- VISUAL MOTION SIMULATOR

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ALTITUDE PROFILES FOR ANALYTICAL MODEL

Wx, r=2391

Wh , r=0

Wind speed, knots

Altitude, ft

1000

500

40

20

0

20

40
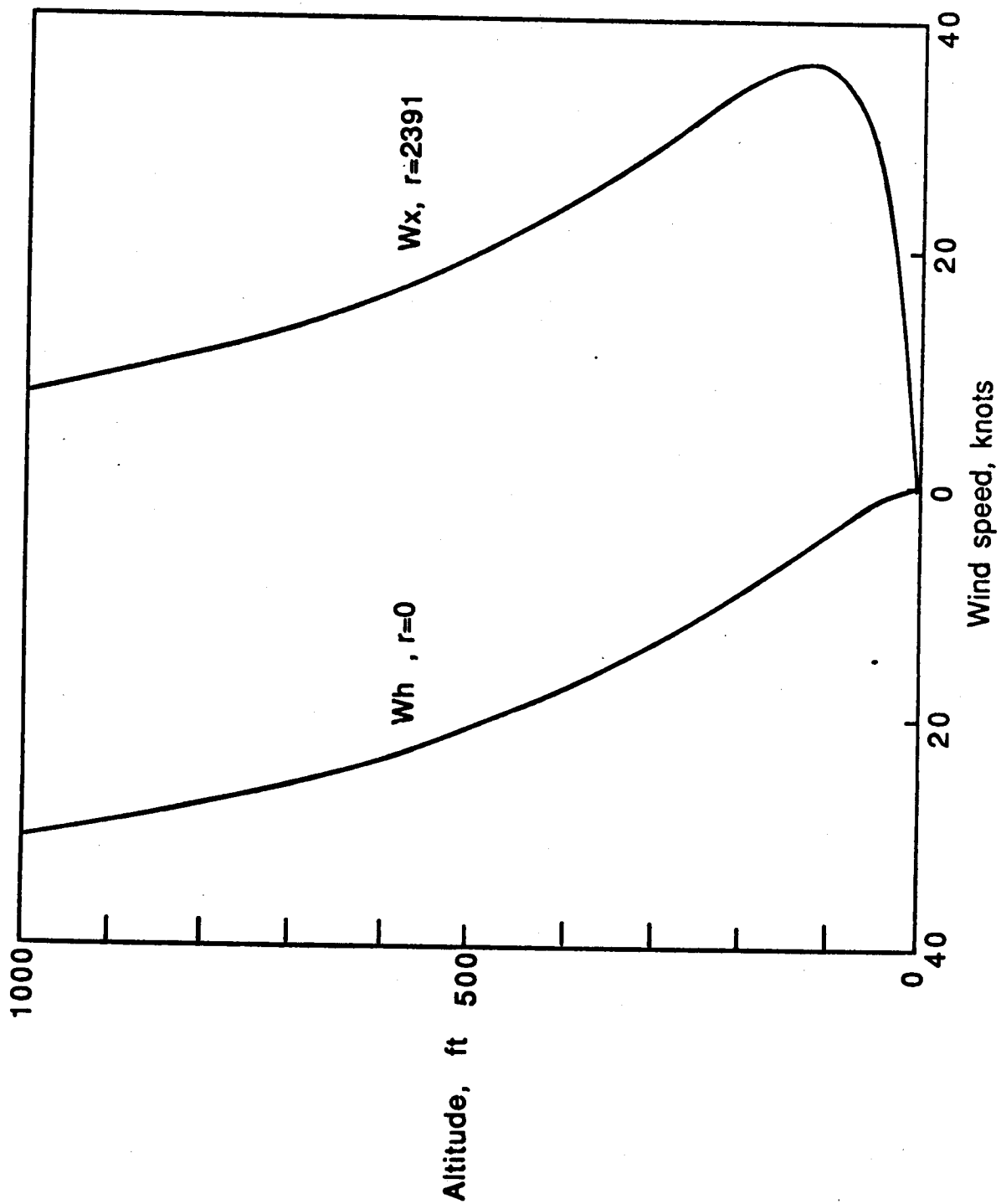
RADIAL AND VERTICAL WIND COMPONENTS
OF ANALYTICAL MICROBURST MODEL

Wx, h=120

Wx, h=500

Wh, h=120

Wh, h=500

Wind speed, knots

Distance from microburst center, ft
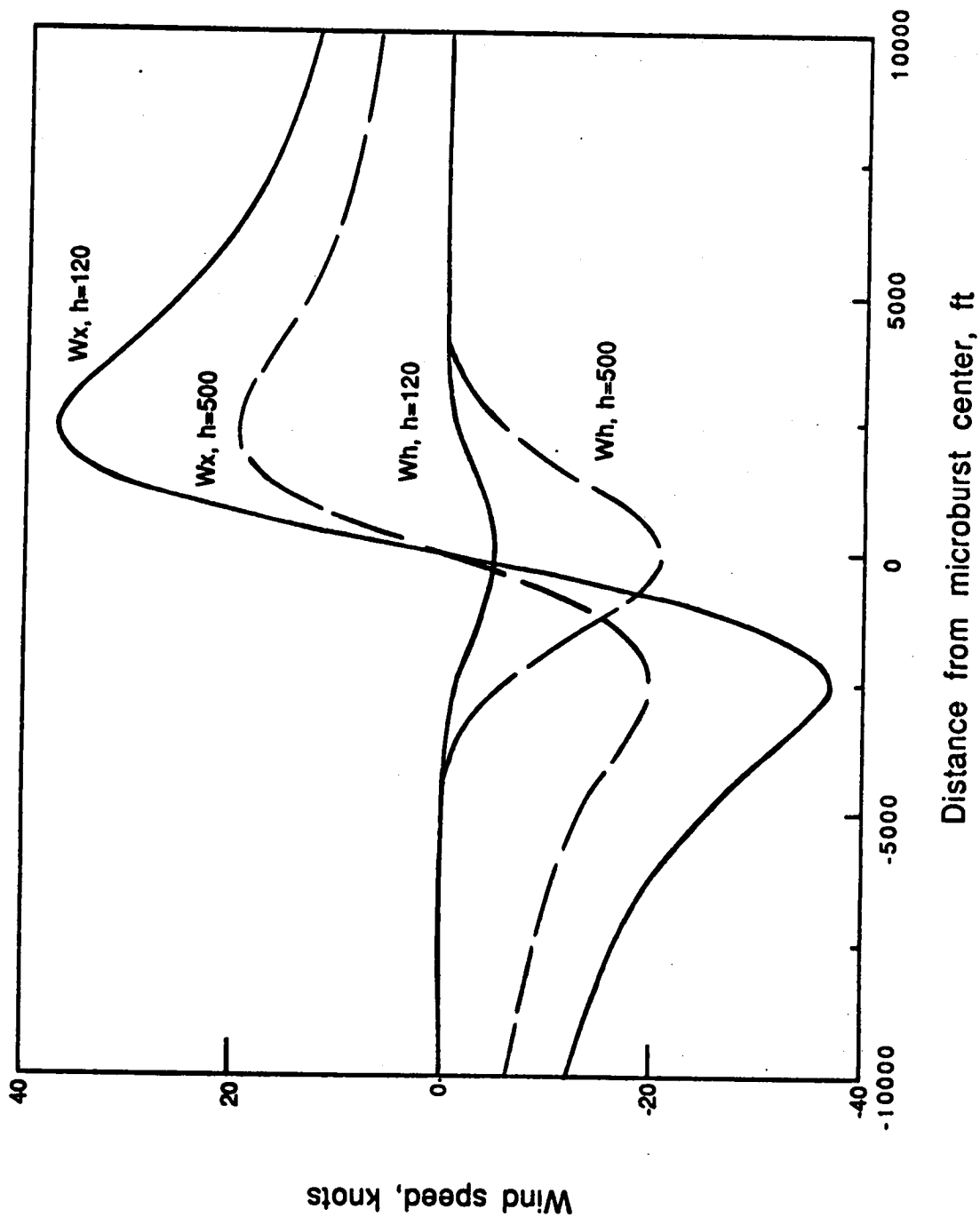
BATCH SIMULATIONS

- POINT-MASS PERFORMANCE MODEL OF B737-100, INCLUDING VARIABLE CONFIGURATION AND AUTOTHROTTLE

- F-FACTOR BASED WIND SHEAR DETECTION

- TESTED 7 RECOVERY STRATEGIES, THREE SELECTED FOR PILOTED TESTS:

  1) TRAINING AID PROCEDURE (BASELINE)

  2) GLIDESLOPE STRATEGY

  3) FLIGHT PATH ANGLE STRATEGY

- RESULTS:

  - BENEFITS OF SHORT-RANGE FORWARD ALERT (5-10 SEC) MUCH GREATER THAN IMPROVING GUIDANCE IN REACTIVE ALERT CASE

  - BASELINE STRATEGY PERFORMANCE SIMILAR TO OTHERS IN REACTIVE ALERT CASE, LESS THAN OTHERS WITH FORWARD ALERT

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BATCH SIMULATION EXAMPLES

THREE STRATEGIES, REACTIVE & FORWARD ALERT
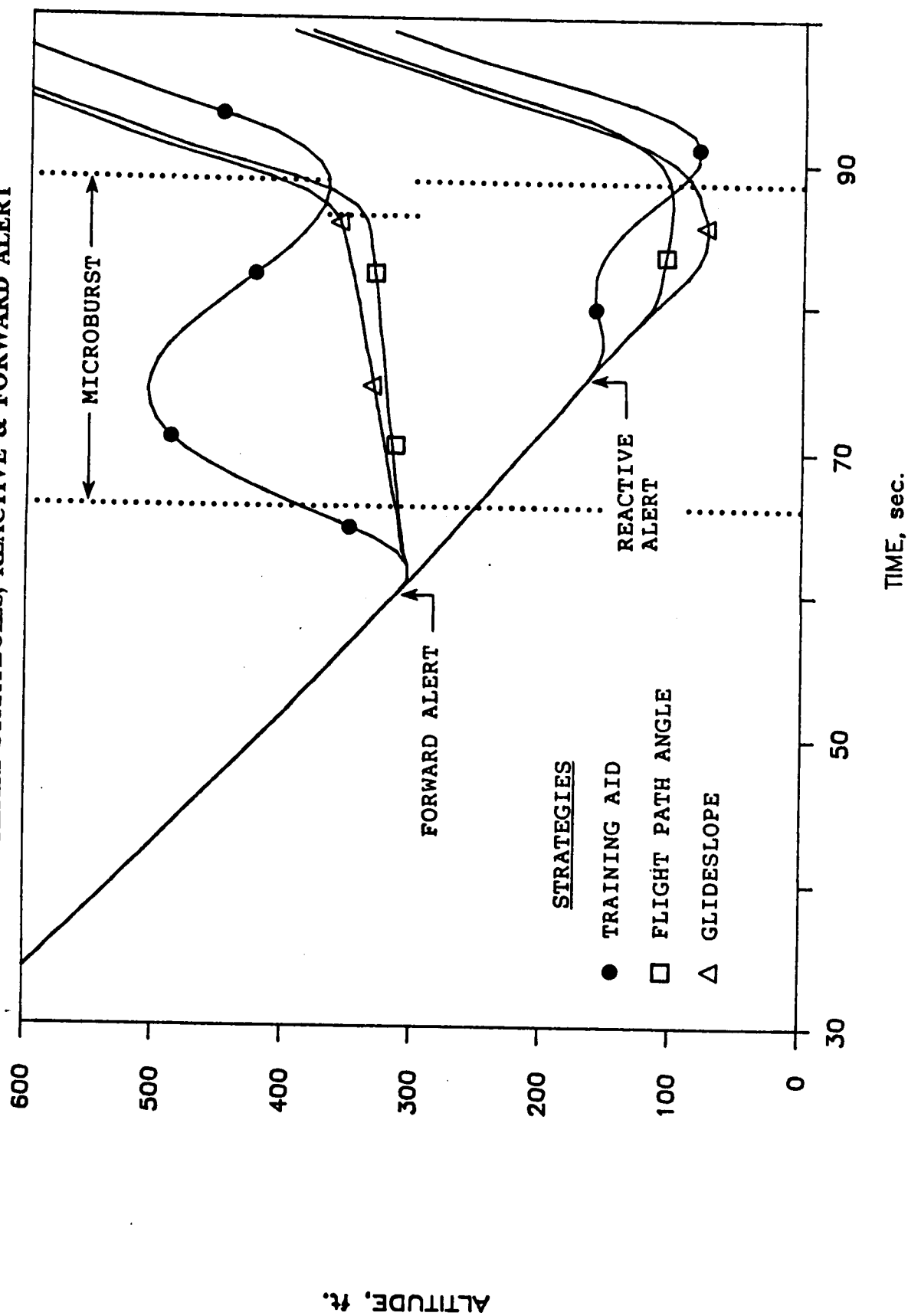
PILOTED SIMULATIONS

- IMPLEMENT THREE STRATEGIES ON ELECTROMECHANICAL ADI

- IMPLEMENT TWO MICROBURST MODELS, TURBULENCE

- IMPLEMENT REACTIVE AND FORWARD-LOOK ALERTING

- TEST TWO ALERT TIMES (-5 AND +10 SEC)

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PILOTED SIMULATION EXAMPLES

THREE STRATEGIES, REACTIVE & FORWARD ALERT
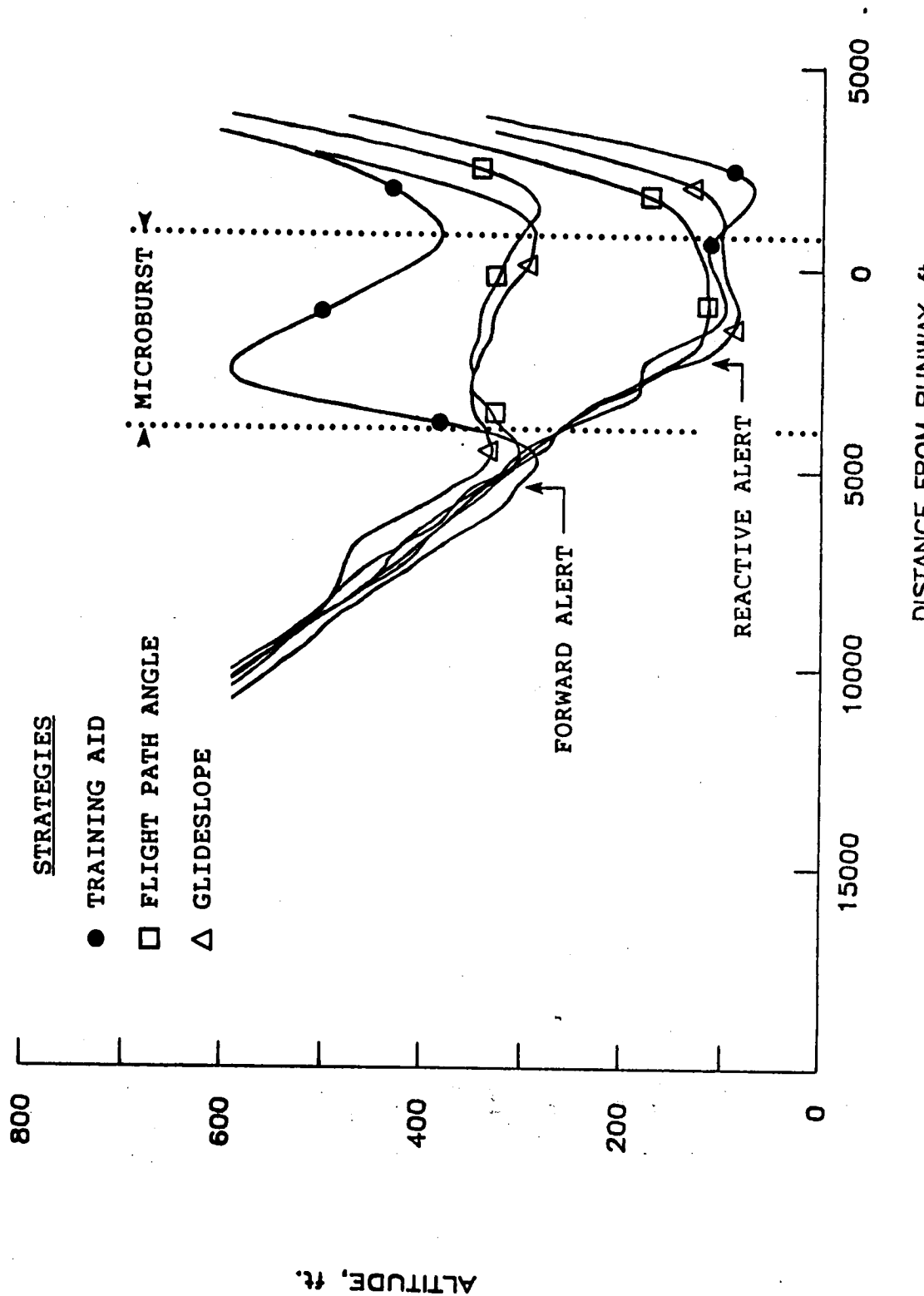
PRELIMINARY TRENDS

- **TWO PILOTS HAVE COMPLETED MATRIX**

- **MINIMUM RECOVERY ALTITUDES SIMILAR WITH ALL THREE STRATEGIES**

- **LARGE PAYOFF SEEN WITH SHORT-RANGE FORWARD LOOK**

  - **NUMEROUS CRASHES AND BELOW 100 FT RECOVERIES WITH REACTIVE ALERT, AVERAGE 110 FT**

  - **LOWEST RECOVERY WITH FORWARD LOOK HAS BEEN 268 FT, AVERAGE 387 FT**

  - **NORMAL GO-AROUND PROCEDURE TRIED WITH FORWARD LOOK, WITH EQUIVALENT PERFORMANCE TO GUIDED PROCEDURES**

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CHANGE IN ENERGY HEIGHT

COMPARISON TO PILOTED APPROACH RUNS
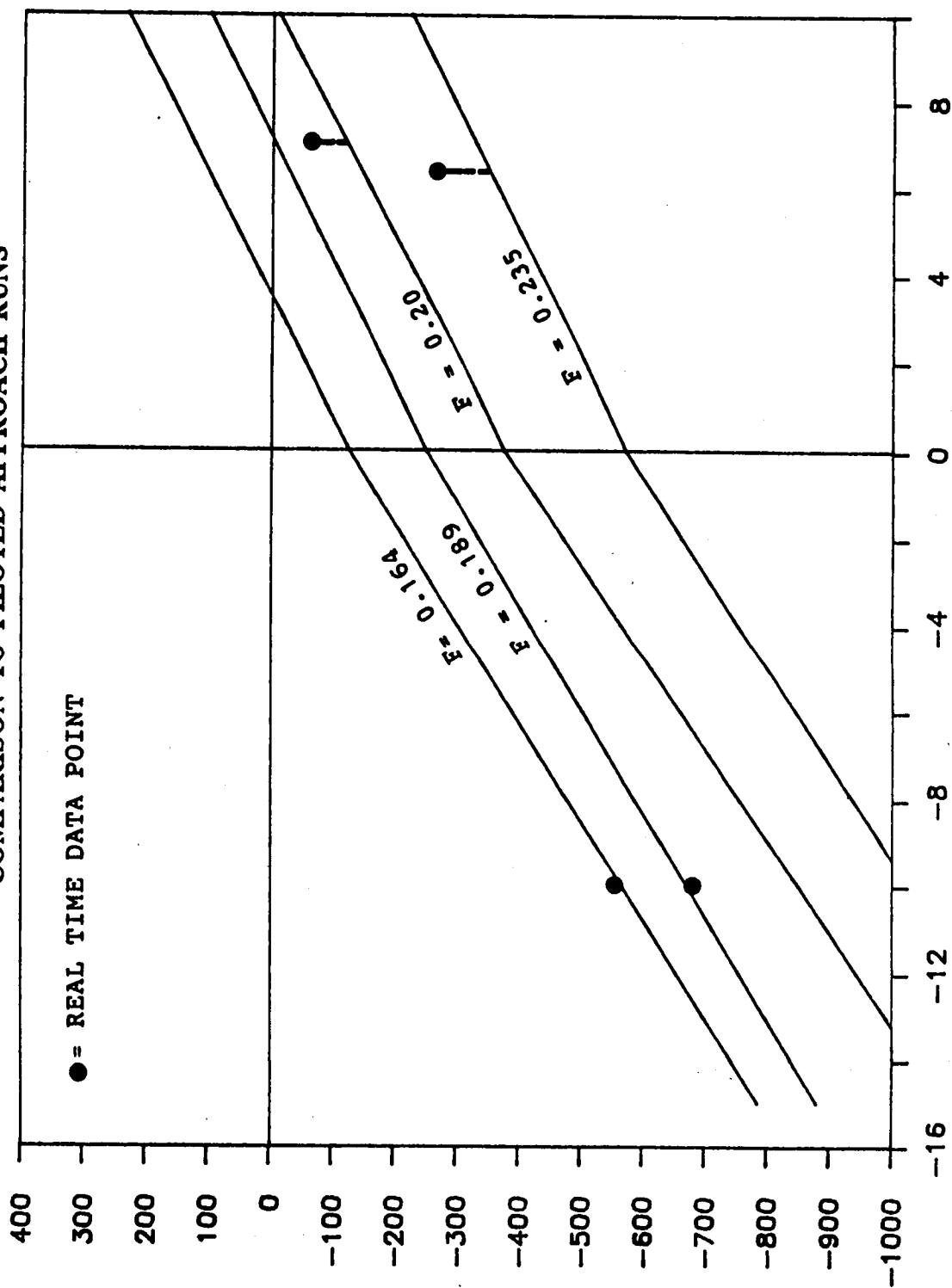
OUTLINE

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CONCLUSIONS

- PREDICTED BENEFITS OF ADVANCED RECOVERY PROCEDURES MAY NOT BE ACHIEVED WHEN MANUALLY FLOWN

- CURRENT TRAINING AID PROCEDURE IS APPROPRIATE FOR MANUALLY FLOWN RECOVERIES FROM A REACTIVE ALERT

- BENEFITS OF FORWARD- LOOK SENSING FAR EXCEED ENHANCED GUIDANCE

- RESEARCH NEEDED IN: - AUTOMATED RECOVERIES
  - FORWARD LOOK HAZARD DISPLAYS
  - COCKPIT INTEGRATION

Session II. Airborne–Flight Management

Analysis and Synthesis of a Wind Shear Detection Algorithm
Kioumars Najmabadi, Boeing

ANALYSIS AND SYNTHESIS

OF A WINDSHEAR DETECTION ALGORITHM

(NASA SUPPORTED)

KIOUMARS NAJMABADI

BOEING COMMERCIAL AIRPLANES

OCTOBER 1988

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OBJECTIVE

- DEVELOP ONBOARD HAZARD-WIND PREDICTION, DETECTION, ALERTING AND GUIDANCE SCHEMES WHICH UTILIZES AMBIENT AND LOOK-AHEAD INFORMATION

- PROVIDE THE FLIGHT CREW WITH THE NECESSARY INFORMATION TO:

  - AVOID WIND SHEAR IF POSSIBLE

  - INITIATE THE NECESSARY RECOVERY MANEUVER

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THE BOEING WINDSHEAR STUDIES TEAM

(NASA SUPPORTED)

GUIDANCE & CONTROL RESEARCH

- Optimal detection filter design
- Alert Boundaries Determination
- Delay effects study

FLIGHT DECK RESEARCH

- Pilot factor data analysis
- Windshear displays and alerting format
- Piloted simulation studies
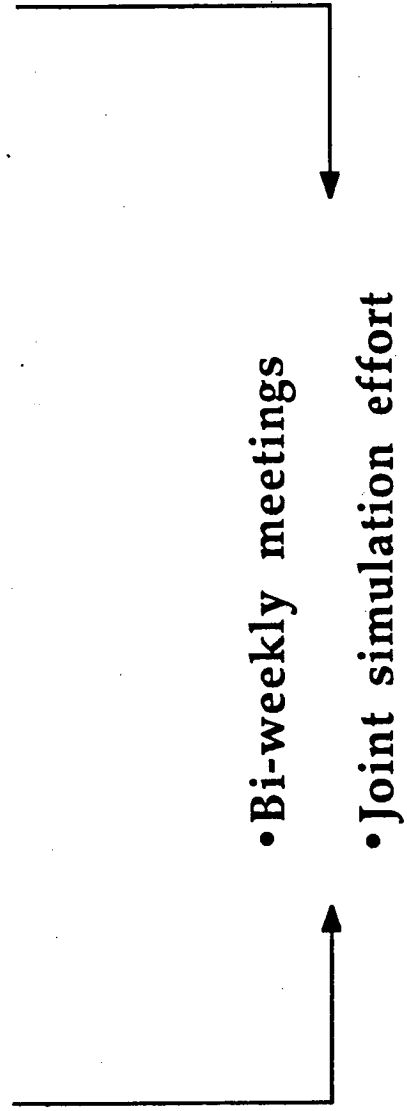
- Bi-weekly meetings
- Joint simulation effort

1987 - 1988 PROGRESS

- DEVELOPED A DIRECTORY OF ATMOSPHERIC DISTURBANCE MODELS AND INTEGRATED THIS WITH NONLINEAR MODELS OF TIME AND ENGINE AIRPLANE ON ENGINEERING WORKSTATION.

- COMPUTED THE EXPECTED NUMBER OF LEVEL-CROSSING OF A SYSTEM OUTPUT SUBJECT TO A RANDOM INPUT.

- APPLIED THE ABOVE RESULTS TO OBTAIN CLOSED-FORM SOLUTIONS FOR THE EXPECTED NUMBER OF LEVEL-CROSSING AS A FUNCTION OF FILTER'S PARAMETER FOR 1st AND 2nd ORDER FILTERS.

1987 - 1988 PROGRESS

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1987 - 1988 PROGRESS   (CONT)

- DEVELOPED A PROGRAM TO COMPUTE FILTER'S PARAMETERS TO MINIMIZE DETECTION TIME FOR A GIVEN NUISANCE ALERT RATE.

- OBTAINED THE PROBABILITY DISTRIBUTION FUNCTIONS FOR PEAKS OF THE F-FACTOR AND NUISANCE ALERT AS FUNCTIONS OF FILTER'S PARAMETERS AND ALERT THRESHOLD.

BOEING

oxh   Earth-fixed axes

$PX_v Y_l$ Body-fixed relative wind axes

$PX_{ve} Y_{le}$ Body-fixed absolute wind axes

BOEING
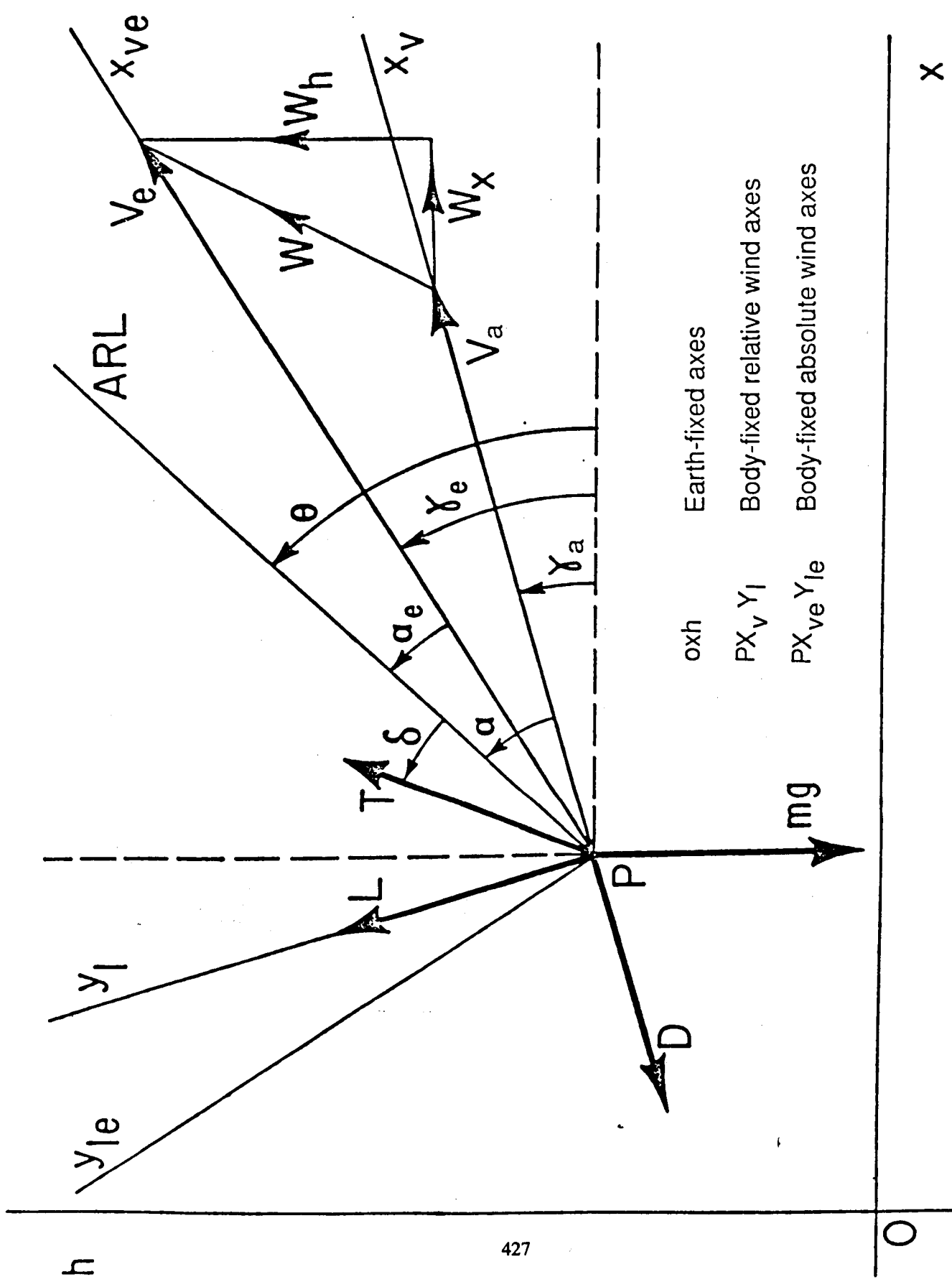
WIND SHEAR HAZARD INDEX

DRAG EQUATION IN RELATIVE WIND-AXES COORDINATE SYSTEM:

$$\frac{T-D}{W} = \frac{\dot{V}_a}{g} + \frac{\dot{h}_I}{V_a} + \frac{\dot{W}_x}{g} - \frac{W_h}{V_a} + \frac{\dot{W}_h}{g}\left(\frac{\dot{h}_a}{V_a}\right)$$

$$\gamma_p \triangleq \frac{\dot{V}_a}{g} + \frac{\dot{h}_I}{V_a} = \frac{1}{V_a}\frac{dE}{dt}$$

$$F \triangleq \frac{\dot{W}_x}{g} - \frac{W_h}{V_a} + \frac{\dot{W}_h}{g}\left(\frac{\dot{h}_a}{V_a}\right) = \text{"WIND SHEAR HIT"}$$

$$\frac{T-D}{W} = \gamma_p + F$$

$$\frac{\dot{W}_x}{g} - \frac{W_h}{V_a} >> \frac{\dot{W}_h}{g}\left(\frac{\dot{h}_a}{V_a}\right)$$

$$F = \frac{\dot{W}_x}{g} - \frac{W_h}{V_a}$$

$$E = Mgh_I + \frac{1}{2} MV_a^2$$

$$E_S = \frac{E}{W} = h_I + \frac{1}{2g} V_a^2$$

$$\frac{dE_s}{dt} = \dot{E}_s = \dot{h}_I + \frac{1}{g} V_a \dot{V}_a$$

DRAG EQUATION:

$$\dot{V}_a = \frac{T}{M} \cos(\alpha + \delta) - \frac{D}{M} - g \sin \gamma_a - \left(\dot{W}_x \cos \gamma_a + \dot{W}_h \sin \gamma_a \right)$$

THEREFORE :

$$\dot{E}_s = \left(\frac{T \cos(\alpha + \delta) - D}{Mg} \right) V_a - \left(\frac{\dot{W}_x \cos \gamma_a + \dot{W}_h \sin \gamma_a}{g} \right) V_a + W_h$$

AIRPLANE ENERGY RATE OF CHANGE DUE TO WIND $= \left(\dfrac{\dot{W}_x + \dot{W}_h \gamma_a}{g} \right) V_a - W_h$

$$V_a \frac{\dot{W}_x}{g} - W_h \; \rangle\rangle \; V_a \frac{\dot{W}_h \gamma}{g}$$

NORMALIZE WITH RESPECT TO VELOCITY :

$$F = \frac{\dot{W}_x}{g} - \frac{W_h}{V_a}$$

$$W_x \longrightarrow \boxed{H(s)} \longrightarrow \dot{W}_x$$

$$H(s) = \frac{s}{(\tau s + 1)}$$

$$\sigma_u = 8 \frac{ft}{sec}$$

$\tau = 25$ sec

$\tau = 2.5$ sec

Threshold

$\dot{W}_x$ (ft / s^2)

Threshold

$\dot{W}_x$ (ft / s^2)

TIME (SEC)

TIME (SEC)

FILTER RESPONSES TO TURBULENCE

BOEING

430
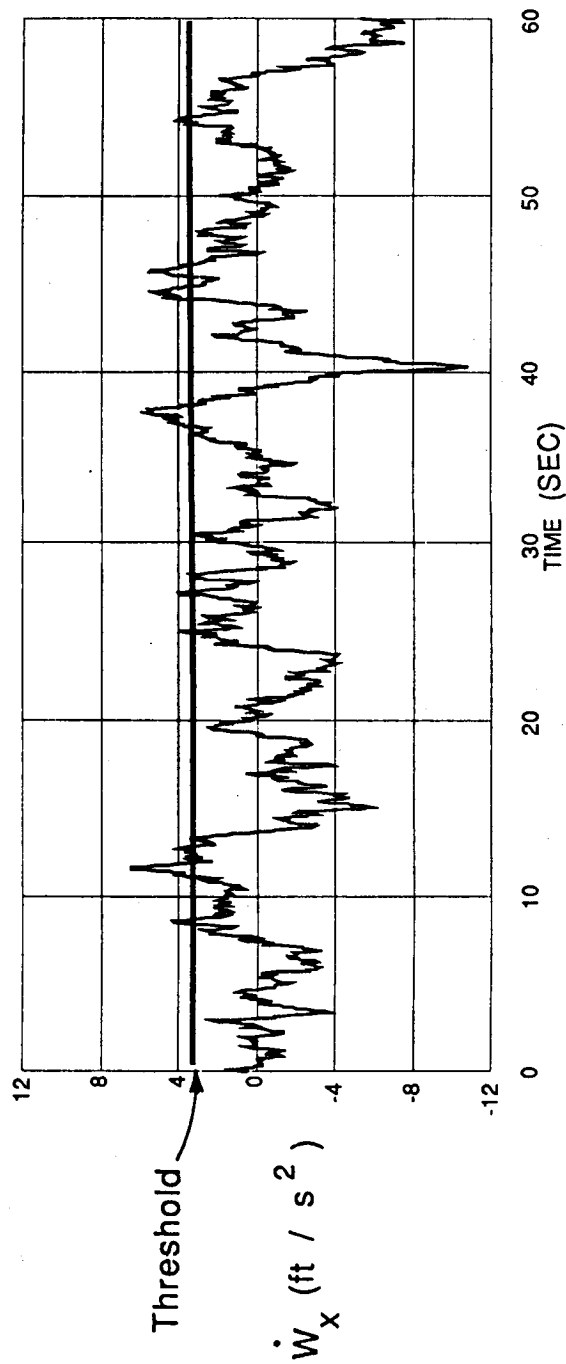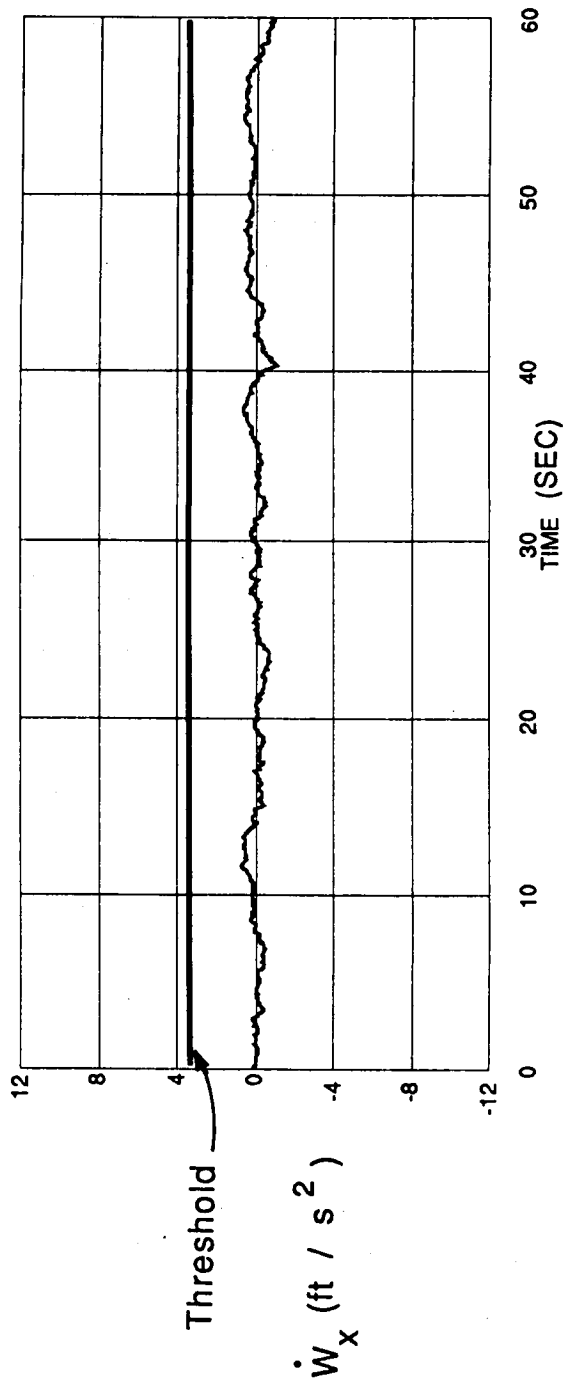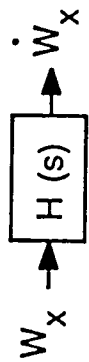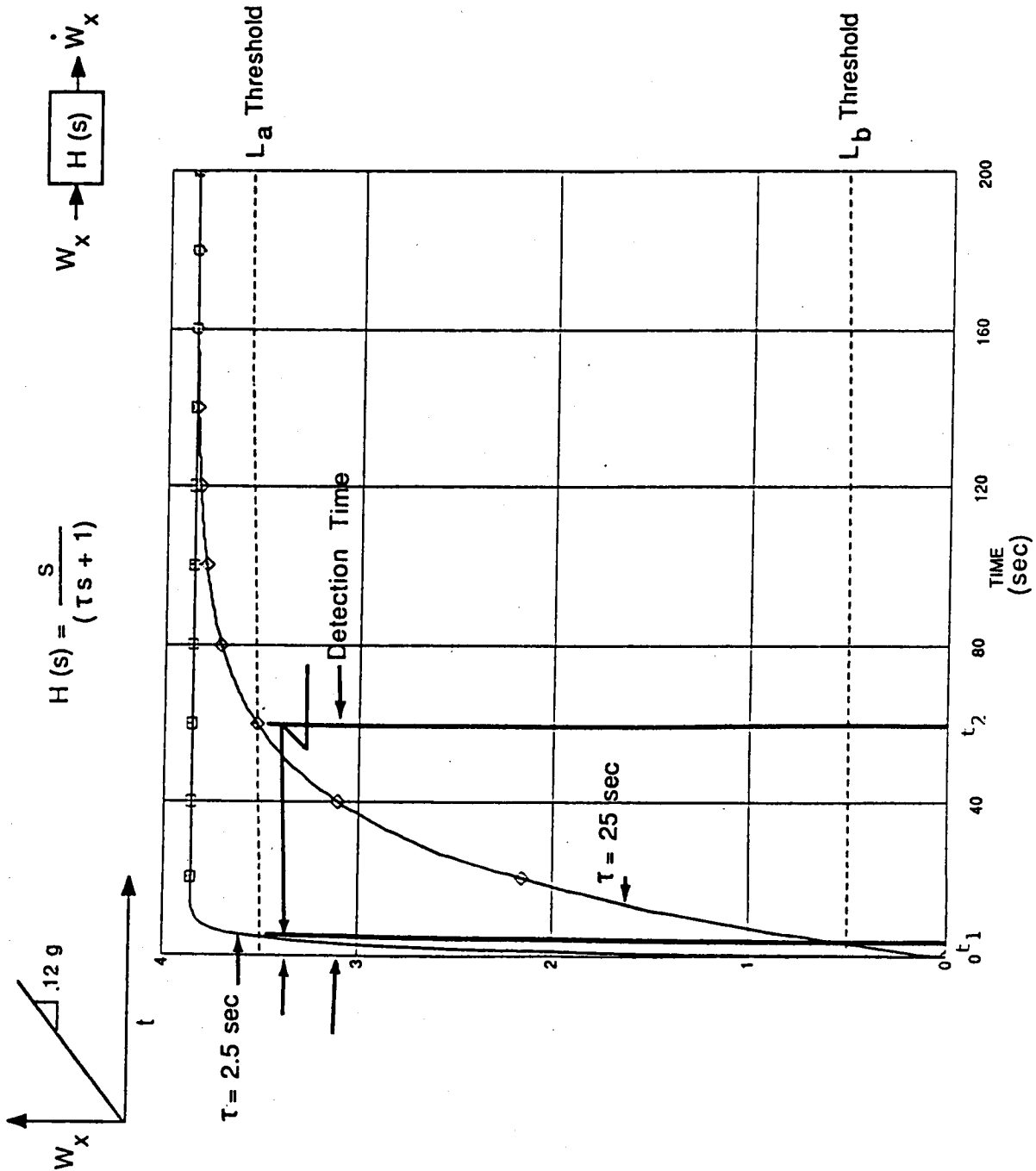
FILTER RESPONSES TO CONSTANT SHEAR

$$H(s) = \frac{s}{(\tau s + 1)}$$

$W_x \longrightarrow \boxed{H(s)} \longrightarrow \dot{W}_x$

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$$G(s) = \frac{1}{(\tau s + 1)}$$

H (s)

$W_x \rightarrow \boxed{s} \rightarrow \boxed{G(s)} \rightarrow \dot{W}_x$
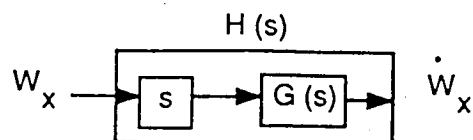
$\tau_f = 2.5$ sec fast $\tau_s = 25$ sec slow

GAIN(DB'S)

FREQ (RAD/SEC)
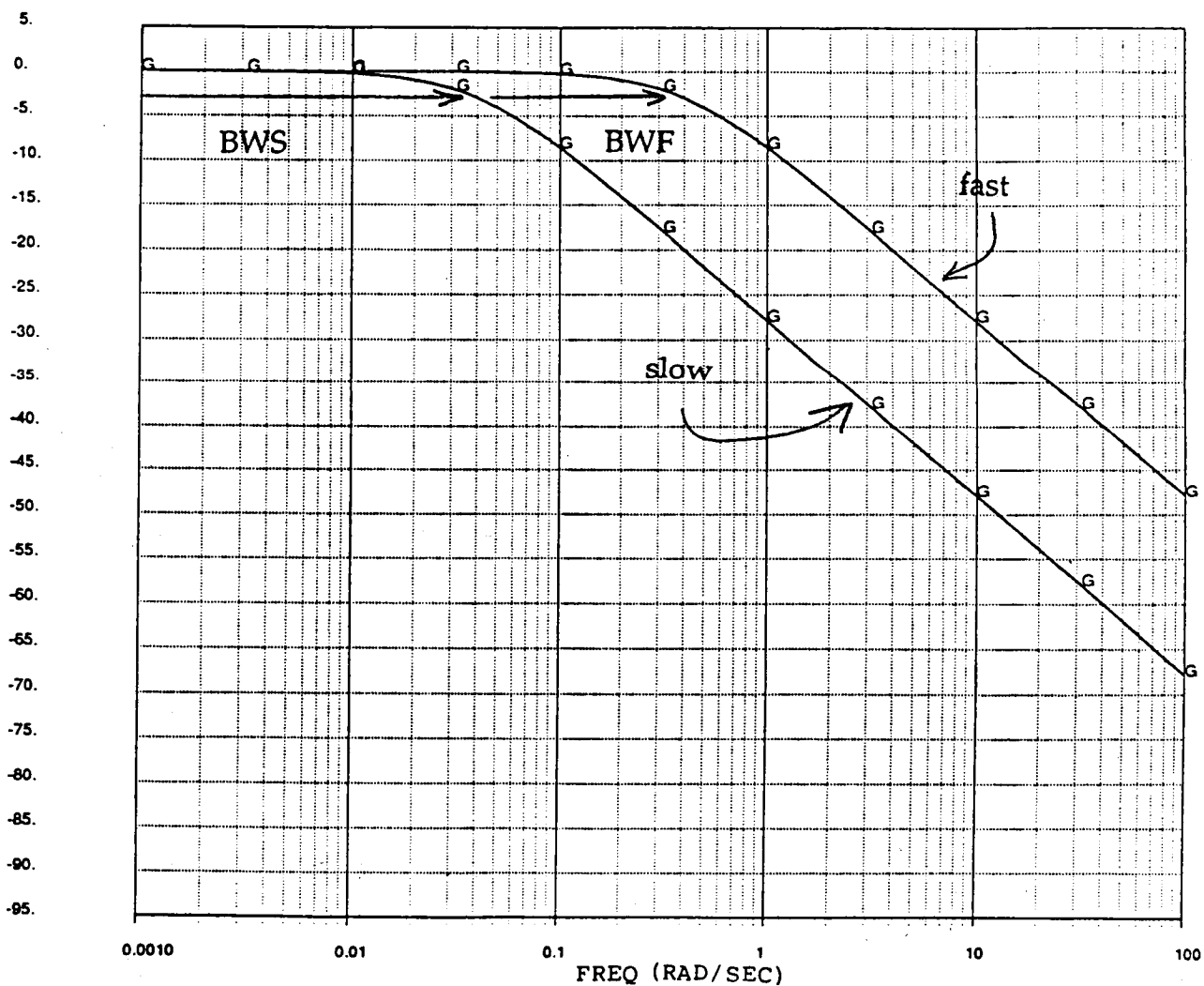
ATTENUATION OF HIGH FREQUENCY
BY FAST AND SLOW FILTERS

BOEING

ALERT BOUNDARIES

$$\frac{\dot{w}_x}{g} - \frac{w_h}{v_a} = L$$

WARNING ALERT
(ENERGY DECREASING)

HEAD TO TAIL

$$\frac{\dot{w}_x}{g}$$

UPDRAFT

$$\frac{w_h}{v_a}$$

ACCIDENT DATA

DOWN DRAFT

$$\frac{\dot{w}_x}{g} - \frac{w_h}{v_a} = -L$$

CAUTIONARY ALERT
(ENERGY INCREASING)

TAIL TO HEAD

BOEING

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ALERT BOUNDARIES

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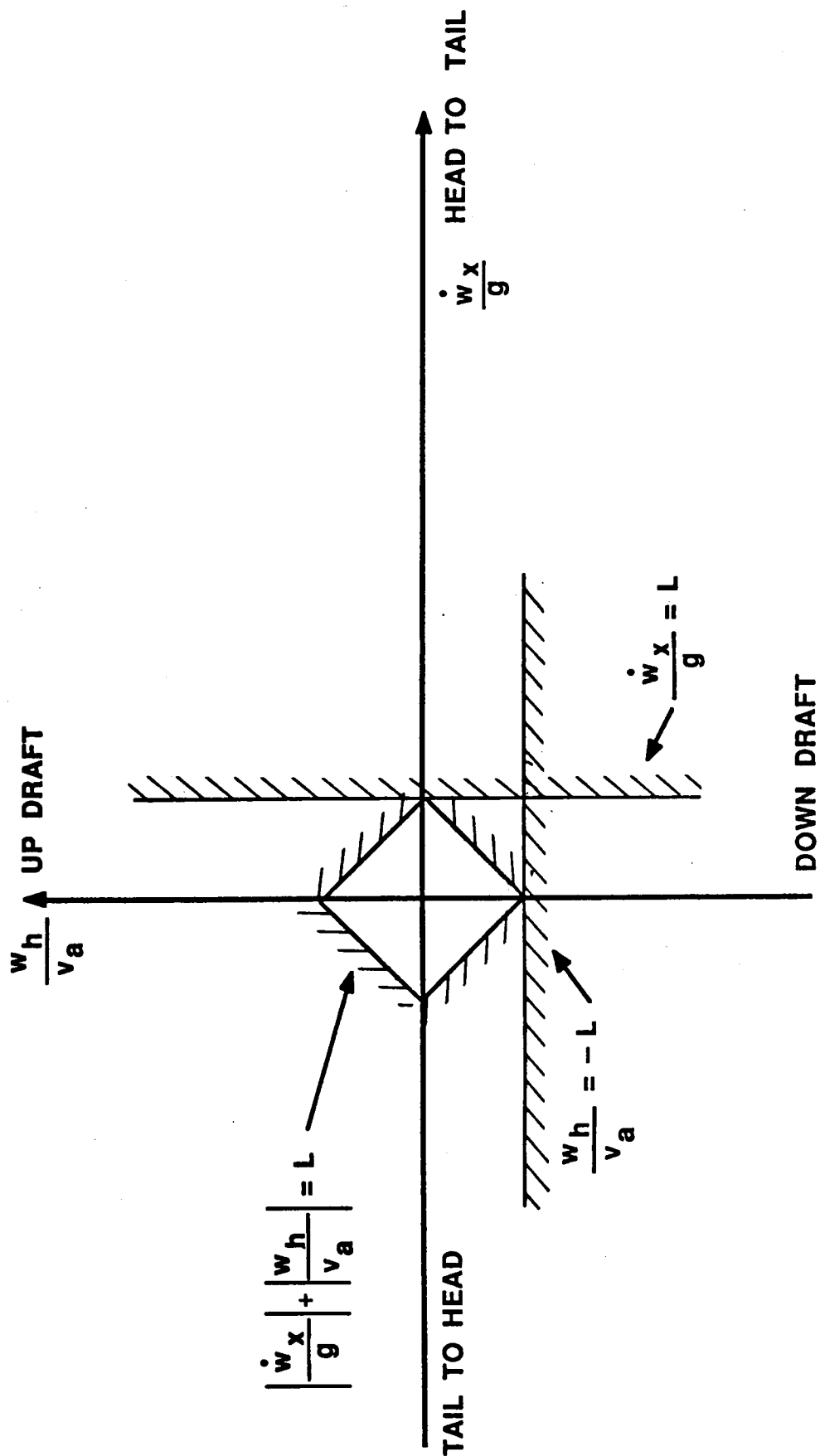
BOEING

FIRST ORDER FILTER
TIME RESPONSE

$$H(s) = \frac{s}{(\tau s + 1)}$$
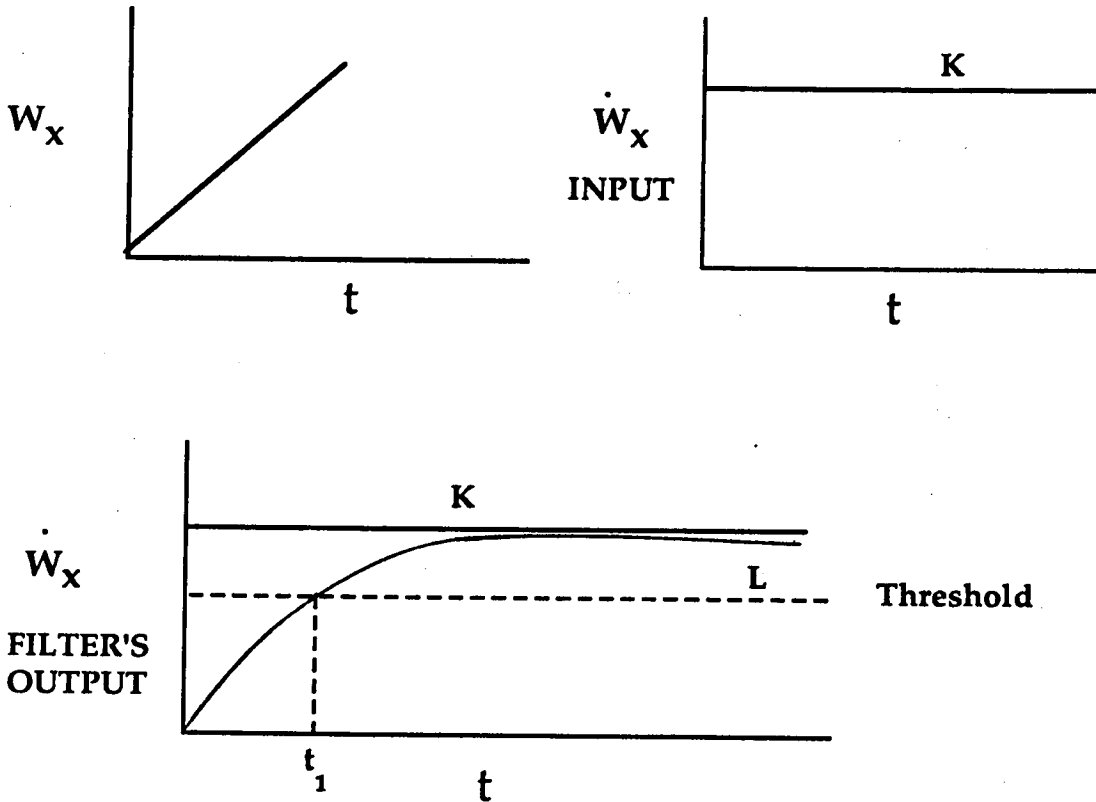
FILTER'S OUTPUT:

$$\dot{W}_x = K - K \, e^{-\frac{t}{\tau}}$$

THRESHOLD CROSSING TIME:

$$t_1 = -\tau \, \ln \left(\frac{K - L}{K} \right)$$

BOEING

$$H(s) = \frac{\omega_n^2 s}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

CASE I: $0 < \zeta < 1$

$$\dot{W}_x = \frac{\omega_n}{\sqrt{1-\zeta^2}} \; e^{-\zeta\omega_n t} \; \sin \omega_n \sqrt{1-\zeta^2}\, t = L$$

CASE II: $\zeta = 1$

$$\dot{W}_x = \omega_n^2 t\, e^{-\omega_n t} = L$$

CASE III: $\zeta > 1$

$$\dot{W}_x = \frac{\omega_n}{2\sqrt{\zeta^2-1}} \; e^{-\left(\zeta - \sqrt{\zeta^2-1}\right)\omega_n t} - \frac{\omega_n}{2\sqrt{\zeta^2-1}} \; e^{-\left(\zeta + \sqrt{\zeta^2-1}\right)\omega_n t} = L$$
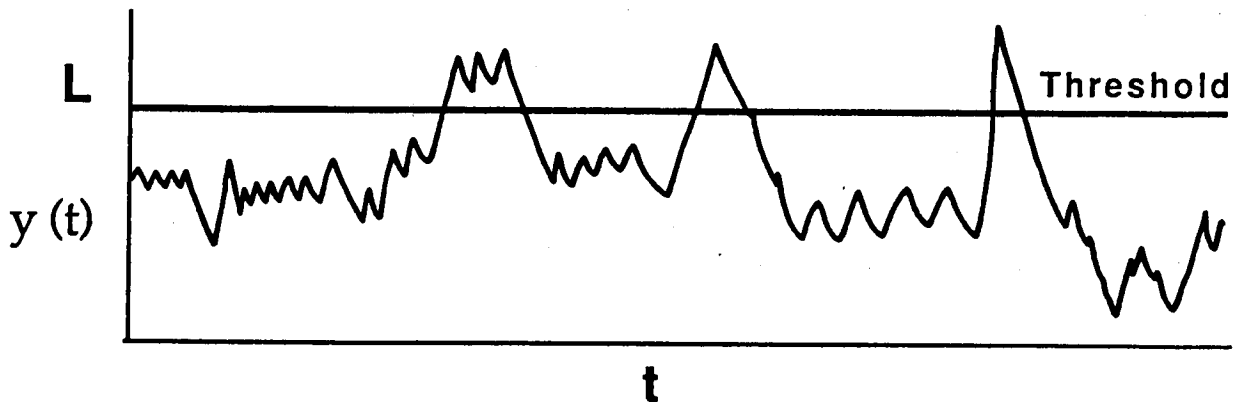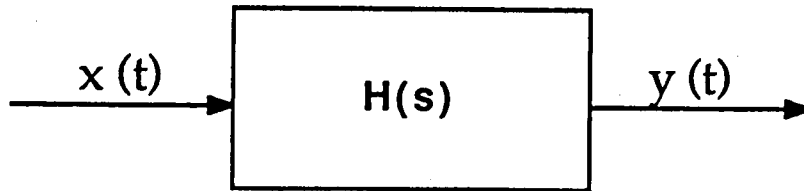
$$N(y = L) = \int_0^\infty \dot{y}\, P(y, \dot{y})\, d\dot{y}\bigg|_{y = L}$$

N (L) = The frequency of crossing the value of L with positive slope per unit time

P (y, ẏ) = Joint probability density of y (t) and ẏ (t)

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ASSUMING THAT y **AND** $\dot{y}$ **ARE STATISTICALLY INDEPENDENT :**

$$P(y, \dot{y}) = P(y) P(\dot{y})$$

$$N(y) = P(y) \int_0^\infty \dot{y} P(\dot{y}) \, d\dot{y}$$

IF y **IS GAUSSIAN :**

$$P(y) = \frac{1}{\left(2\pi \sigma_y^2\right)^{1/2}} e^{-\frac{1}{2}(y/\sigma_y)^2}$$

$$P(\dot{y}) = \frac{1}{\left(2\pi \sigma_{\dot{y}}^2\right)^{1/2}} e^{-\frac{1}{2}(\dot{y}/\sigma_{\dot{y}})^2}$$

THEN

$$N(y) = \frac{\sigma_{\dot{y}}}{2\pi \sigma_y} e^{-\frac{1}{2}(y/\sigma_y)^2}$$

BOEING

$$\sigma_y^2 = E\left(y^2\right) - \left[E\left(y\right)\right]^2$$

LET $\quad E\left(y\right) = 0, \quad E\left(\dot{y}\right) = 0$

THEN

$$\sigma_y^2 = E\left(y^2\right) = \overline{y^2}, \qquad \sigma_{\dot{y}}^2 = E\left(\dot{y}^2\right) = \overline{\dot{y}^2}$$

$$\sigma_y^2 = \overline{y^2} = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \Phi_{yy}\ d\omega$$

$$\sigma_{\dot{y}}^2 = \overline{\dot{y}^2} = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \omega^2\ \Phi_{yy}\ d\omega$$

BOEING

White Noise (R) → | shaping filter $H_T(s)$ | → Turbulence → | system $H_S(s)$ | → y
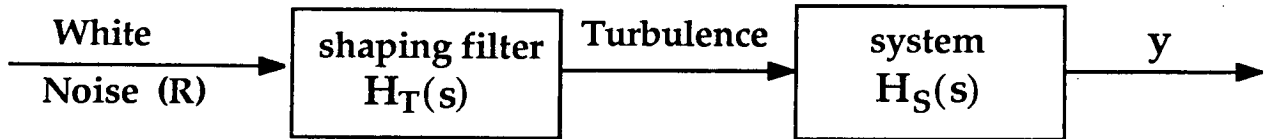
$$\Phi_{yy}(\omega) = R\, H_T(j\omega)\, H_T(-j\omega)\, H_S(j\omega)\, H_S(-j\omega)$$

FOR THE PRESENT CASE:

$$H_T(s) = \frac{\sigma_u \sqrt{2}}{\sqrt{\gamma}} \frac{1}{(\gamma^{-1}s + 1)} \qquad \text{DRYDEN TURBULENCE}$$

$$H_S(s) = \frac{s}{(\tau s + 1)^2} \qquad \text{FILTER TRANSFER FUNCTION}$$

WHERE

$$\gamma = \frac{V_a}{L_s}$$

AND

L_s = SCALE LENGTH

V_a = AIRSPEED

BOEING

FIRST ORDER FILTER
(HORIZONTAL WIND COMPONENT)

$$\text{white noise} \longrightarrow \boxed{\frac{\sigma_u\sqrt{2\gamma}}{s+\gamma}} \xrightarrow{\text{Turbulence}} \boxed{\frac{s}{(\tau s+1)}} \longrightarrow \dot{W}_x$$

$$\boxed{\frac{s}{\beta s+1}} \longrightarrow \ddot{W}_x$$
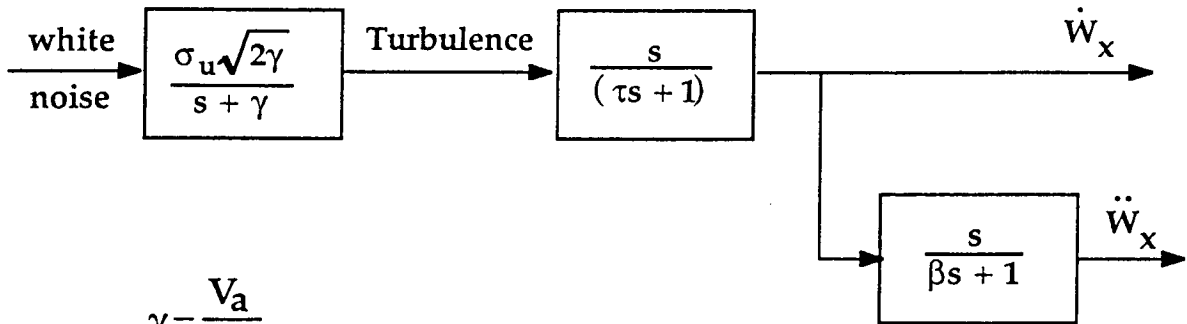
$$\gamma = \frac{V_a}{L_s}$$

$$\Phi_{\dot{W}_x}(s) = \frac{2\sigma_u^2 \gamma s^2}{(\gamma^2 - s^2)(\tau^2 s^2 - 1)}$$

$$\Phi_{\ddot{W}_x}(s) = \frac{2\sigma_u^2 \gamma s^4}{(\gamma^2 - s^2)(\tau^2 s^2 - 1)(\beta^2 s^2 - 1)}$$

$$\sigma_{\dot{W}_x}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{\dot{W}_x}(\omega)\, d\omega = \frac{\sigma_u^2 \gamma}{\tau(1+\tau\gamma)}$$

$$\sigma_{\ddot{W}_x}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{\ddot{W}_x}(\omega)\, d\omega = \frac{\sigma_u^2 \gamma[1+\gamma(\tau+\beta)]}{\beta\tau(\gamma\tau+1)(\tau+\beta)(1+\gamma\beta)}$$

$$N(L) = \frac{\sigma_{\ddot{W}_x}}{2\pi\sigma_{\dot{W}_x}} e^{-\frac{1}{2}\left(\frac{L}{\sigma_{\dot{W}_x}}\right)^2} = \quad \text{EXPECTED NUMBER OF THRESHOLD CROSSING PER UNIT TIME}$$

BOEING

441

SECOND ORDER FILTER
(HORIZONTAL WIND COMPONENT)

white noise $\rightarrow$ $\boxed{\dfrac{\sigma_u \sqrt{2\gamma}}{s + \gamma}}$ $\rightarrow$ $\boxed{\dfrac{\alpha s}{(s+a)(s+b)}}$ $\rightarrow$ $\dot{W}_x$

$\rightarrow \boxed{s} \rightarrow \ddot{W}_x$

$$\gamma = \frac{V_a}{L_s}$$

$$\Phi_{\dot{W}_x}(s) = \frac{2\sigma_u^2 \gamma \alpha^2 s^2}{(s^2 - \gamma^2)(s^2 - a^2)(s^2 - b^2)}$$

$$\Phi_{\ddot{W}_x}(s) = \frac{2\sigma_u^2 \gamma \alpha^2 s^4}{(\gamma^2 - s^2)(s^2 - a^2)(s^2 - b^2)} \cdot$$

$$\sigma_{\dot{W}_x}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{\dot{W}_x}(\omega)\, d\omega = \frac{\sigma_u^2 \gamma \alpha^2}{(\gamma + a)(\gamma + b)(a + b)}$$

$$\sigma_{\ddot{W}_x}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{\ddot{W}_x}(\omega)\, d\omega = \sigma_u^2 \alpha^2 \gamma \left[\frac{\gamma(a+b) + ab}{(\gamma + a)(\gamma + b)(a + b)} \right]$$

$$N(L) = \frac{\sigma_{\ddot{W}_x}}{2\pi\, \sigma_{\dot{W}_x}}\, e^{-\frac{1}{2}\left(\frac{L}{\sigma_{\dot{W}_x}}\right)^2} = \begin{array}{l}\text{EXPECTED NUMBER OF}\\ \text{THRESHOLD CROSSING}\\ \text{PER UNIT TIME}\end{array}$$

BOEING

442

FIRST ORDER FILTER
(VERTICAL WIND COMPONENT)

white noise $\rightarrow$ $\boxed{\dfrac{\sigma_h \sqrt{3}\,\gamma \left(s + \dfrac{\gamma}{\sqrt{3}}\right)}{(s+\gamma)^2}}$ $\xrightarrow{\text{Turbulence}}$ $\boxed{\dfrac{a}{(s+a)}}$ $\xrightarrow{\;} W_h$

$\boxed{s} \xrightarrow{\;} \dot{W}_h$
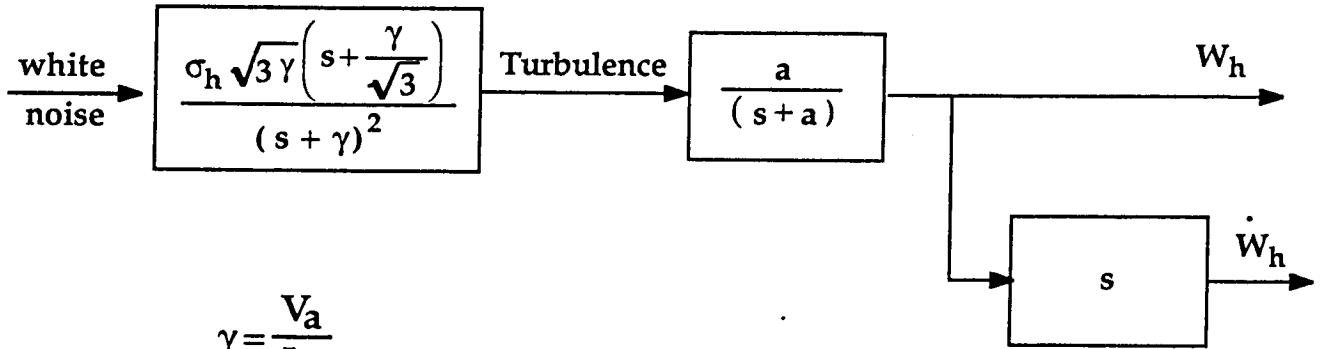
$$\gamma = \frac{V_a}{L_s}$$

$$\Phi_{W_h}(s) = \frac{\sigma_h^2\, 3\gamma\, a^2 \left(\dfrac{\gamma^2}{3} - s^2\right)}{\left(\gamma^2 - s^2\right)^2 \left(a^2 - s^2\right)}$$

$$\Phi_{\dot{W}_h}(s) = \frac{-s^2\, \sigma_h^2\, 3\gamma\, a^2 \left(\dfrac{\gamma^2}{3} - s^2\right)}{\left(\gamma^2 - s^2\right)^2 \left(a^2 - s^2\right)}$$

$$\sigma_{W_h}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{W_h}(\omega)\, d\omega = \frac{\sigma_h^2\, a\,(\gamma + 2a)}{2\,(\gamma + a)^2}$$

$$\sigma_{\dot{W}_h}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{\dot{W}_h}(\omega)\, d\omega = \frac{\sigma_h^2\, a^2\, \gamma\,(2\gamma + 3a)}{2\,(\gamma + a)^2}$$

$$N(L) = \frac{\sigma_{\dot{W}_h}}{2\pi\, \sigma_{W_h}}\, e^{-\frac{1}{2}\left(\frac{L}{\sigma_{W_h}}\right)^2} = \begin{array}{l}\text{EXPECTED NUMBER OF}\\ \text{THRESHOLD CROSSING}\\ \text{PER UNIT TIME}\end{array}$$

BOEING

443

SECOND ORDER FILTER
(VERTICAL WIND COMPONENT)

$$\gamma = \frac{V_a}{L_s}$$

$$\Phi_{W_h}(s) = \frac{\sigma_h^2\, 3\gamma\, a^2\, b^2 \left(\dfrac{\gamma^2}{3} - s^2\right)}{\left(\gamma^2 - s^2\right)^2 \left(a^2 - s^2\right)\left(b^2 - s^2\right)}$$

$$\Phi_{\dot{W}_h}(s) = \frac{-s^2\, \sigma_h^2\, 3\gamma\, a^2\, b^2 \left(\dfrac{\gamma^2}{3} - s^2\right)}{\left(\gamma^2 - s^2\right)^2 \left(a^2 - s^2\right)\left(b^2 - s^2\right)}$$

$$\sigma_{W_h}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{W_h}(\omega)\, d\omega = \frac{\sigma_h^2\, ab \left(\gamma^3 + 2\gamma^2(a+b) + \gamma(a^2+b^2) + 5ab\gamma + 2ab^2 + 2a^2b\right)}{2(b+a)(\gamma+a)^2(\gamma+b)^2}$$

$$\sigma_{\dot{W}_h}^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \Phi_{\dot{W}_h}(\omega)\, d\omega = \frac{\sigma_h^2\, a^2 b^2 \gamma \left(\gamma^2 + 2\gamma(a+b) + 3ab\right)}{2(b+a)(\gamma+a)^2(\gamma+b)^2}$$

$$N(L) = \frac{\sigma_{\dot{W}_h}}{2\pi \sigma_{W_h}}\, e^{-\frac{1}{2}\left(\frac{L}{\sigma_{W_h}}\right)^2} = \text{EXPECTED NUMBER OF THRESHOLD CROSSING PER UNIT TIME}$$

444

$$\dot{x}(t) = A(t)\,x(t) + B(t)\,w(t)$$

$$y = Cx$$

$$x(t_0) = x_0$$

WHERE

$$E[w(t)\,w(\tau)] = R\,\delta(t - \tau)$$

$$E[x_0] = m_0$$

$$E\left[(x_0 - m_0)(x_0 - m_0)^T\right] = Q_0$$

THE STATE COVARIANCE MATRIX Q :

$$\dot{Q}(t) = AQ + QA^T + BRB^T$$

$$Q(t_0) = Q_0$$

STEADY-STATE VALUE OF Q :

$$AQ + QA^T + BRB^T = 0 \qquad \text{(LYAPUNOV EQUATION)}$$

THE OUTPUT COVARIANCE MATRIX P :

$$P = CQC^T$$

BOEING

SECOND ORDER FILTER
(HORIZONTAL WIND COMPONENT)

$$
\begin{array}{c}
\text{w(t)} \\
\text{white noise} \\
\text{(R)}
\end{array}
\longrightarrow
\boxed{\dfrac{\sigma_u\sqrt{2\gamma}}{s+\gamma}}
\xrightarrow{\text{Turbulence}}
\boxed{\dfrac{\text{abs}}{(a+s)(b+s)}}
\xrightarrow{\dot{W}_x}
$$
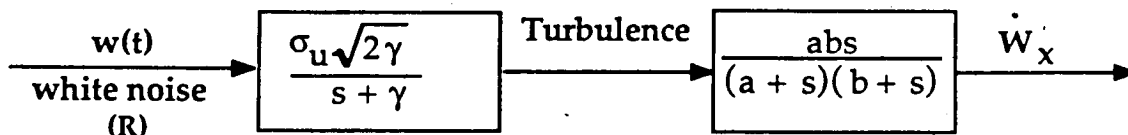
$$\dot{x}(t) = A(t)\,x(t) + B(t)\,w(t)$$

$$y = Cx$$

DEFINE :

$$
x = \begin{bmatrix} W_x \\ \dot{W}_x \\ \ddot{W}_x \end{bmatrix}
$$

$$
y = \begin{bmatrix} \dot{W}_x \\ \ddot{W}_x \end{bmatrix} =
\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}
\begin{bmatrix} W_x \\ \dot{W}_x \\ \ddot{W}_x \end{bmatrix}
$$

STATE MODEL :

$$
\begin{bmatrix} \dot{W}_x \\ \ddot{W}_x \\ \dddot{W}_x \end{bmatrix} =
\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -A_3 & -A_2 & -A_1 \end{bmatrix}
\begin{bmatrix} W_x \\ \dot{W}_x \\ \ddot{W}_x \end{bmatrix} +
\begin{bmatrix} 0 \\ 0 \\ \sigma_u\sqrt{2ab} \end{bmatrix} w
$$

WHERE :

$$A_1 = a + b + \gamma$$

$$A_2 = ab + \gamma b + \gamma a$$

$$A_3 = ab\gamma$$

BOEING

446

SECOND ORDER FILTER
(VERTICAL WIND COMPONENT)
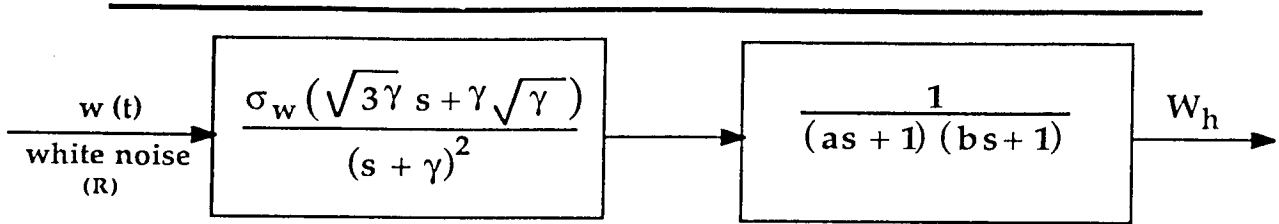
$$\frac{W_h}{w} = \frac{N}{w} \cdot \frac{W_h}{N} = \frac{1}{(s+\gamma)^2 (as+1)(bs+1)} \cdot \sigma_w (\sqrt{3\gamma}\, s + \gamma\sqrt{\gamma})$$

$$\dot{x}(t) = A(t)\, x(t) + B(t)\, w(t)$$

$$y = Cx$$

DEFINE :

$$x = \begin{bmatrix} \dot{N} \\ \ddot{N} \\ \dddot{N} \\ \ddddot{N} \end{bmatrix} \quad ; \quad y = \begin{bmatrix} W_h \\ \dot{W}_h \end{bmatrix}$$

STATE MODEL :

$$\dot{x} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ A_1 & A_2 & A_3 & A_4 \end{bmatrix} x + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \sigma_w \end{bmatrix} w$$

$$y = \begin{bmatrix} W_h \\ \dot{W}_h \end{bmatrix} = \begin{bmatrix} \gamma\sqrt{\gamma} & \sqrt{3\gamma} & 0 & 0 \\ 0 & \gamma\sqrt{\gamma} & \sqrt{3\gamma} & 0 \end{bmatrix} x$$

WHERE :

$$A_1 = \gamma^2$$

$$A_2 = \frac{2\gamma + \gamma^2 a + \gamma^2 b}{ab}$$

$$A_3 = \frac{1 + 2\gamma a + 2\gamma b + \gamma^2 ab}{ab}$$

$$A_4 = -\frac{(a + b + 2\gamma ab)}{ab}$$

BOEING

$$F = \frac{\dot{W}_x}{g} - \frac{W_h}{V_a}$$

$$E(F) = \frac{1}{g} E(\dot{W}_x) - \frac{1}{V_a} E(W_h)$$

$$\sigma_F^2 = \frac{1}{g^2} \sigma_{\dot{W}_x}^2 + \frac{1}{V_a^2} \sigma_{W_h}^2$$

$$\sigma_{\dot{F}}^2 = \frac{1}{g^2} \sigma_{\ddot{W}_x}^2 + \frac{1}{V_a^2} \sigma_{\dot{W}_h}^2$$

$$N(L) = \frac{\sigma_{\dot{F}}}{2\pi \sigma_F} e^{-\frac{1}{2}\left(\frac{L}{\sigma_F}\right)^2}$$

$$H(S) = \frac{S}{(\tau S + 1)^2}$$

L = THRESHOLD = .15g

Positive slope threshold crossings per hour as a function of Dryden Gust intensity for various filter time constants tau.

Number of threshold crossings per hr, N(L).

RMS Gust intensity, sigma u (ft/s).

$\tau = 1.0$

$\tau = 1.5$

$\tau = 2.0$

τ INCREASING

$\tau = 2.5$

τ	
1.00	+
1.50	◇
2.00	×
2.50	□
3.00	*
3.50	○
4.00	+

BOEING

449
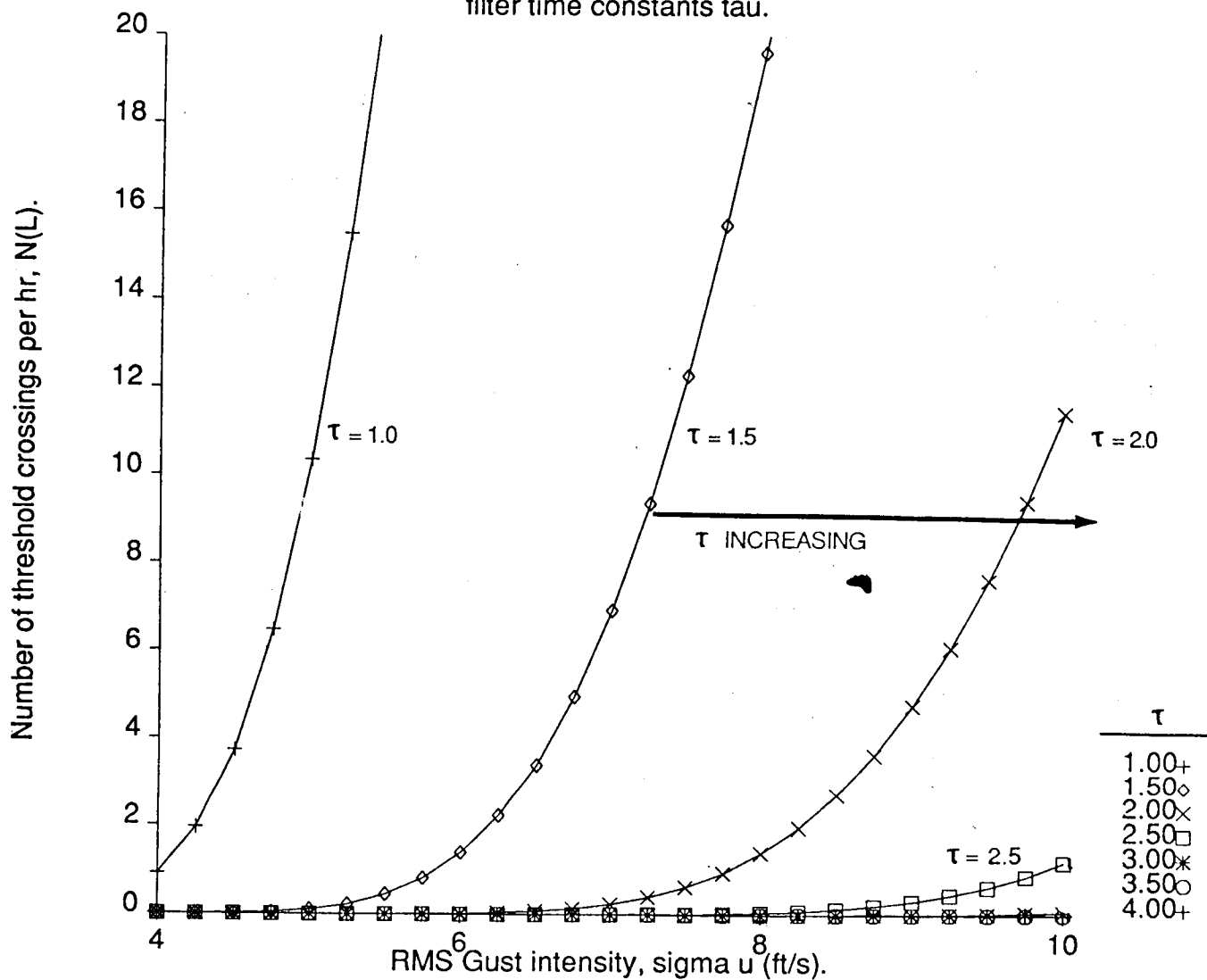
$$H(S) = \frac{S}{(\tau S + 1)^2}$$

$$L = .15g$$

Number of Positive slope threshold crossings per hr vs. Filter coefficient (tau) due to Dryden turbulence of various intensities.

Positive slope threshold crossings per hr.

σ_u INCREASING

Filter coefficient Tau.

σ_u FPS	
4.0	+
6.0	◇
8.0	×
10.0	□
12.0	✳

BOEING

450

$$H(S) = \frac{S}{(3S + 1)^2}$$

Positive slope threshold crossings per hour as a function of Dryden Gust intensity for various thresholds, L.

THRESHOLD INCREASING

L = .07

L = .09

L = .11

L = .13

L	
0.07	+
0.09	◊
0.11	×
0.13	□
0.15	✳
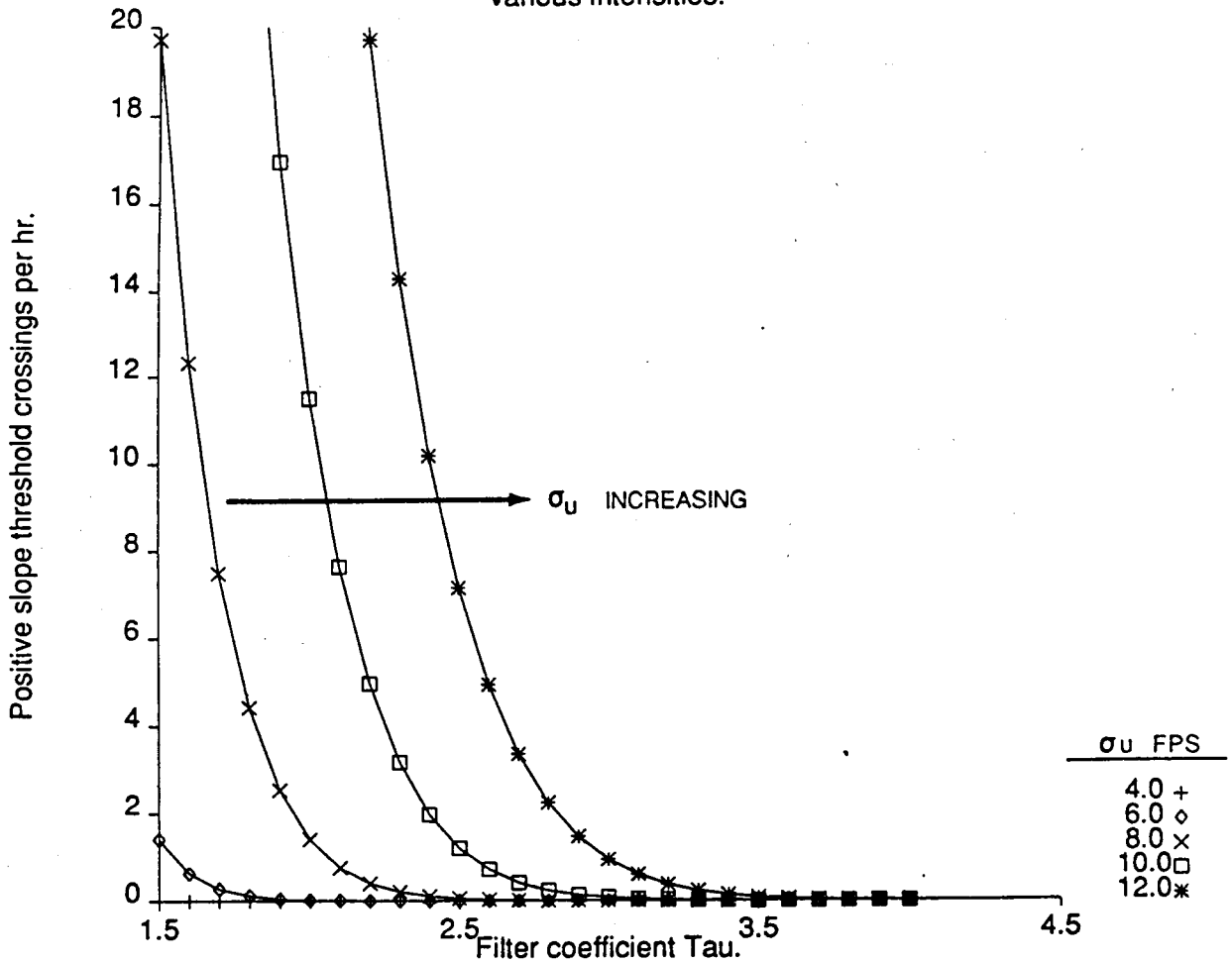
BOEING

$$H(S) = \frac{S}{(3S+1)^2}$$

Positive slope threshold crossings per hour as
a function of threshold L, for various
Dryden gust intensities, sigma_u.

	σ_u FPS	
	4.0	+
	6.0	◇
	8.0	×
	10.0	□
	12.0	＊

σ_u INCREASING

Positive slope threshold crossings per hr, N(L).

Threshold Coefficient, (threshold/g)

BOEING

452
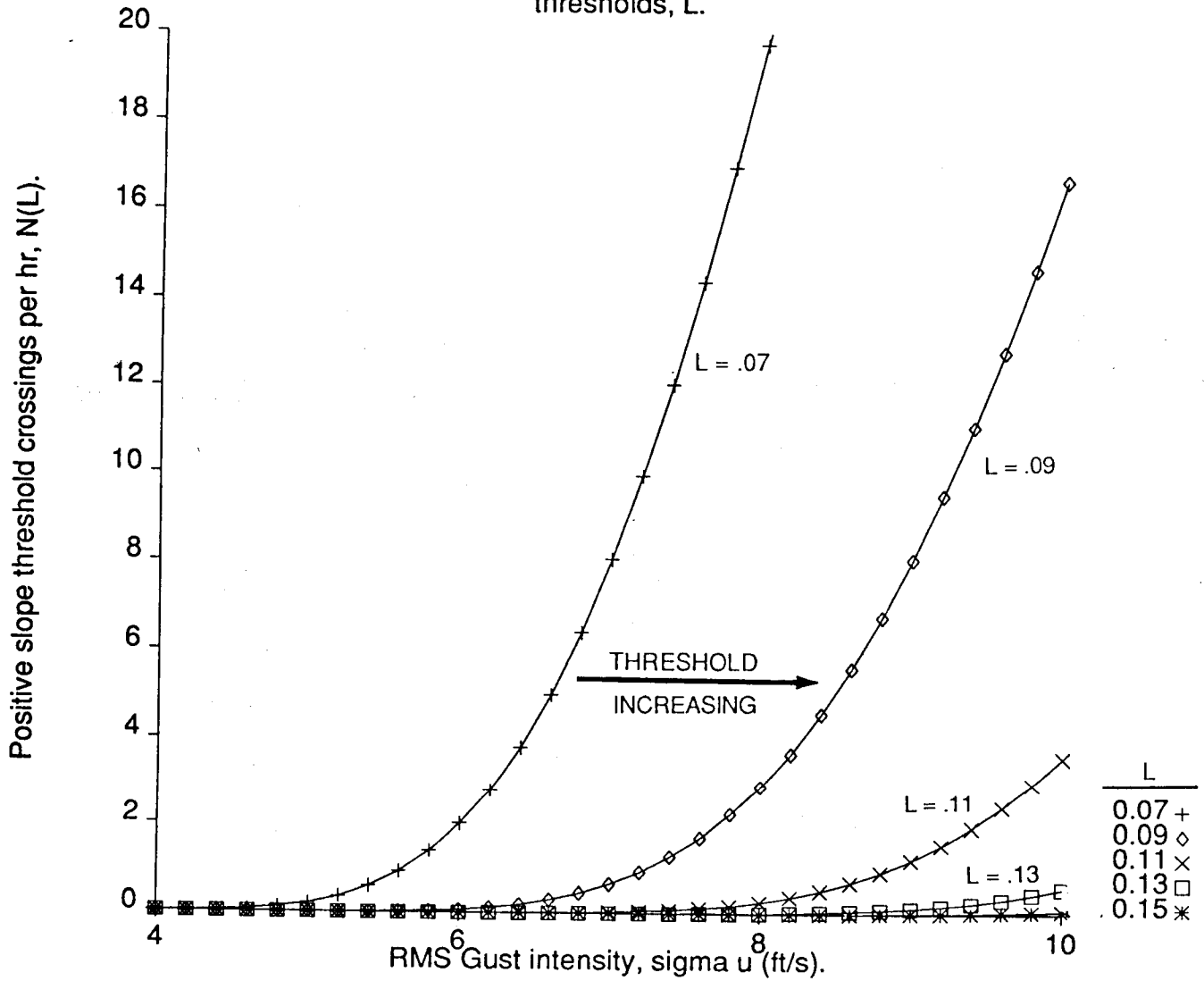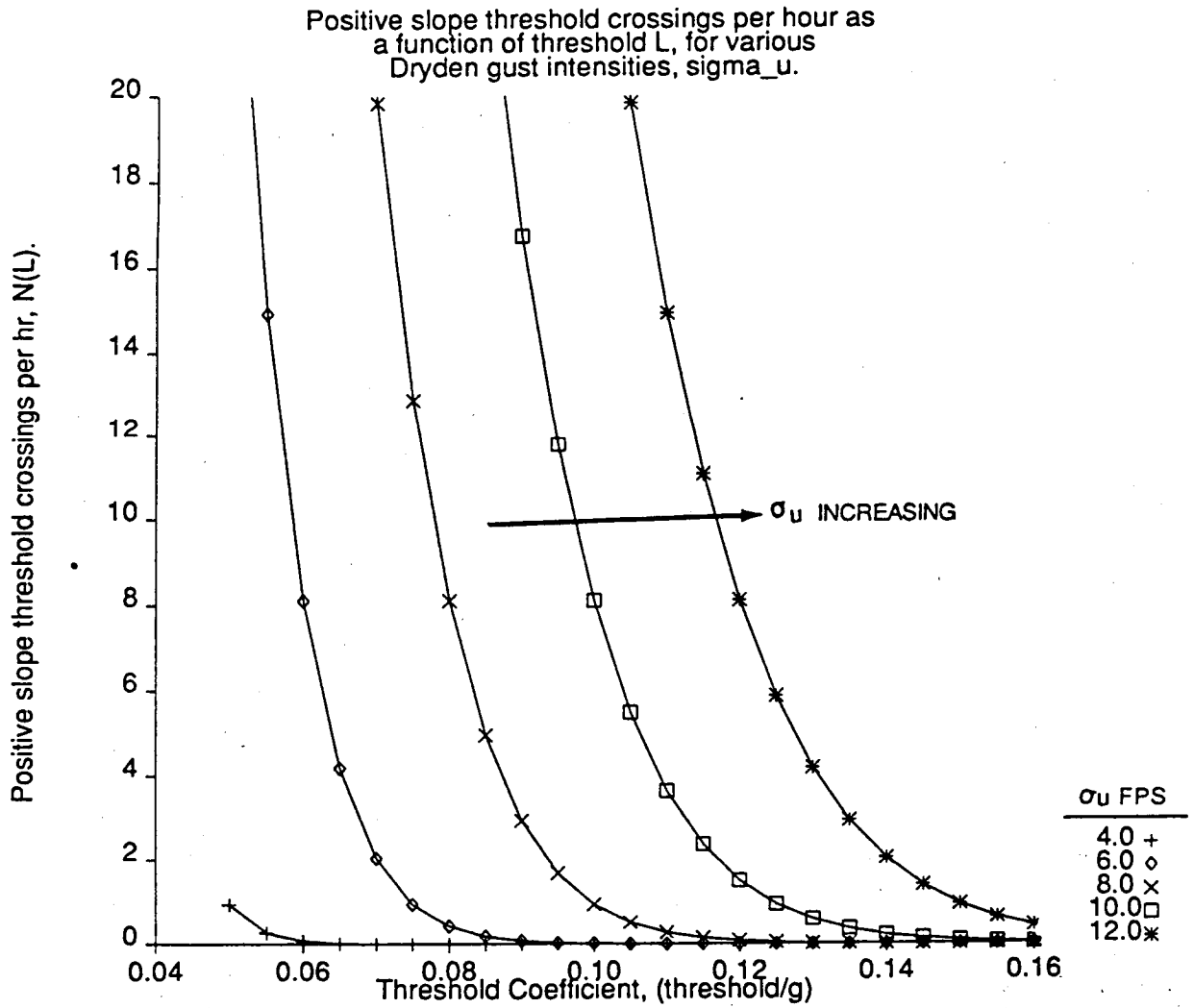
$$H(S) = \frac{S}{(\tau S + 1)^2}$$

L = THRESHOLD = .15g

Detection time as a function of constant shear
intensity for various filter time constants.

τ INCREASING

Detection time (s).

Shear (knot/s).

τ	
2.000	+
3.000	◇
4.000	×

BOEING

453
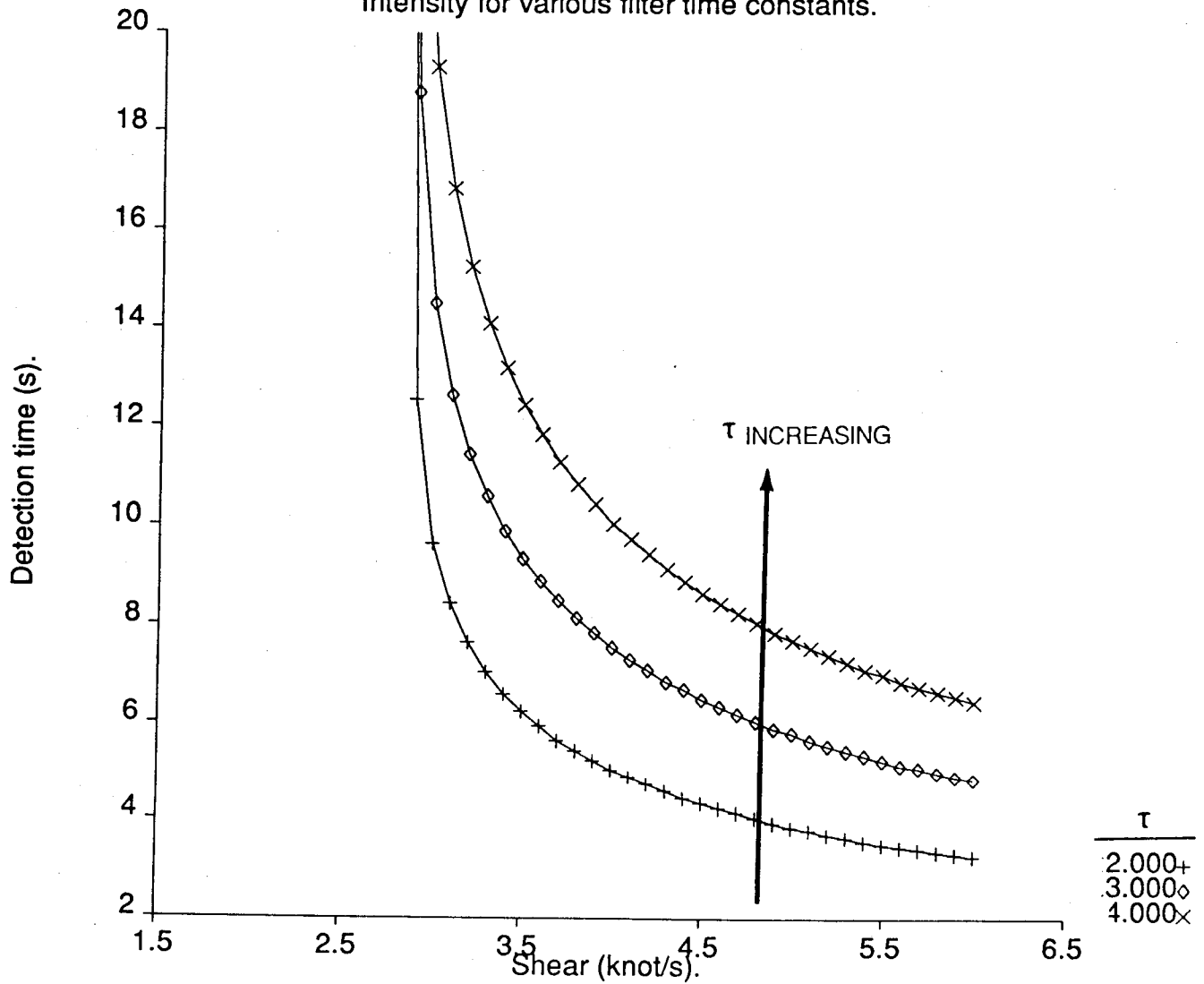
$$H(S) = \frac{S}{(\tau S + 1)^2}$$

$$L = .15g$$

Detection time vs. filter time constant tau
for various constant shear levels.
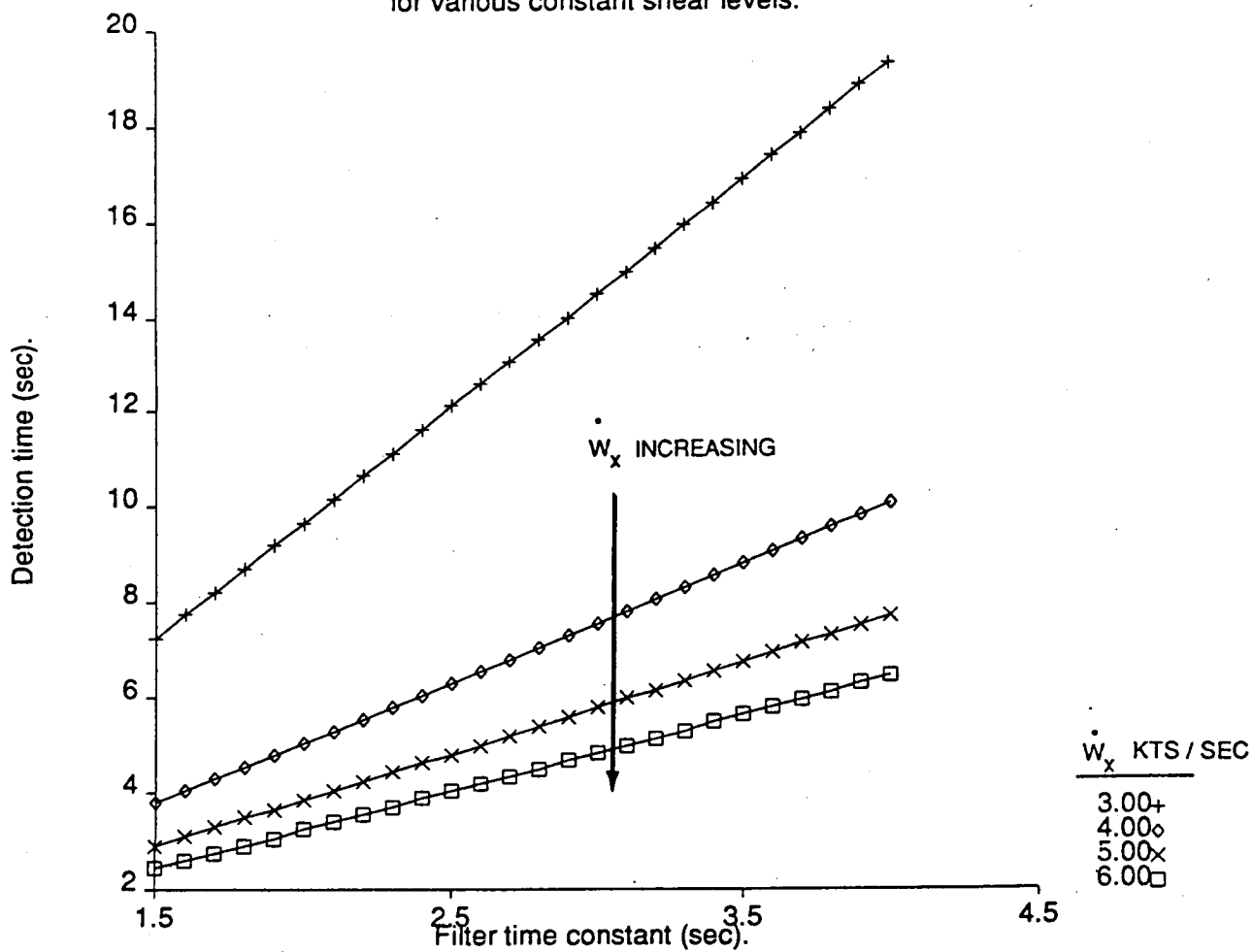
Detection time (sec).

20

18

16

14

12

10

8

6

4

2

$\dot{W}_x$ INCREASING

1.5   2.5   3.5   4.5

Filter time constant (sec).

$\dot{W}_x$ KTS / SEC

3.00 +
4.00 ◇
5.00 ✕
6.00 ☐

BOEING

454

$$H(S) = \frac{S}{(3S+1)^2}$$

Detection time as a function of constant shear
intensity for various thresholds L.

THRESHOLD
INCREASING

L / g	
0.15	+
0.14	◇
0.13	×
0.12	□
0.11	✳
0.10	○

BOEING

455

$$H(S) = \frac{S}{(3S+1)^2}$$

Detection time vs. threshold level
for various constant shear levels.

$\dot{W}_x$ INCREASING

Detection time (sec).

Threshold Coefficient, (threshold/g)

$\dot{W}_x$ KTS / SEC	
1.50	+
2.00	◇
2.50	×
3.00	□
3.50	✳
4.00	○

BOEING

456

$$H(S) = \frac{S}{(TS+1)^2}$$

$$\sigma_u = 8 \, FT/SEC$$

Detection time as a function of shear intensity for second
order filter having varying nuisance alert rates
due to Dryden gust. L = .15 lu = 500, v = 228

N (L)		τ
0.50	+	2.17
1.00	◇	2.06
1.50	×	1.99
2.00	□	1.95
3.00	✳	1.88
4.00	○	1.82

N (L)
INCREASING

BOEING

457
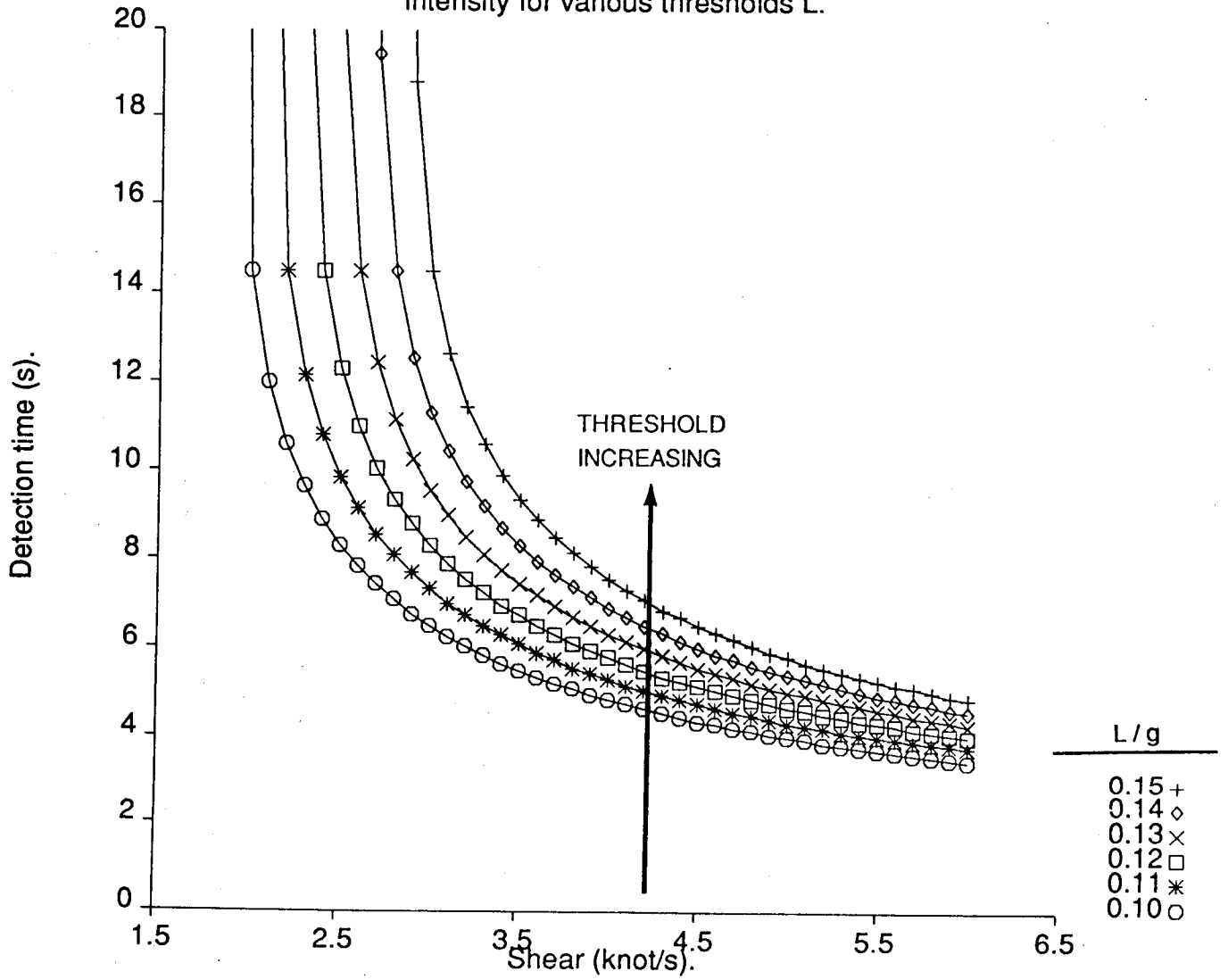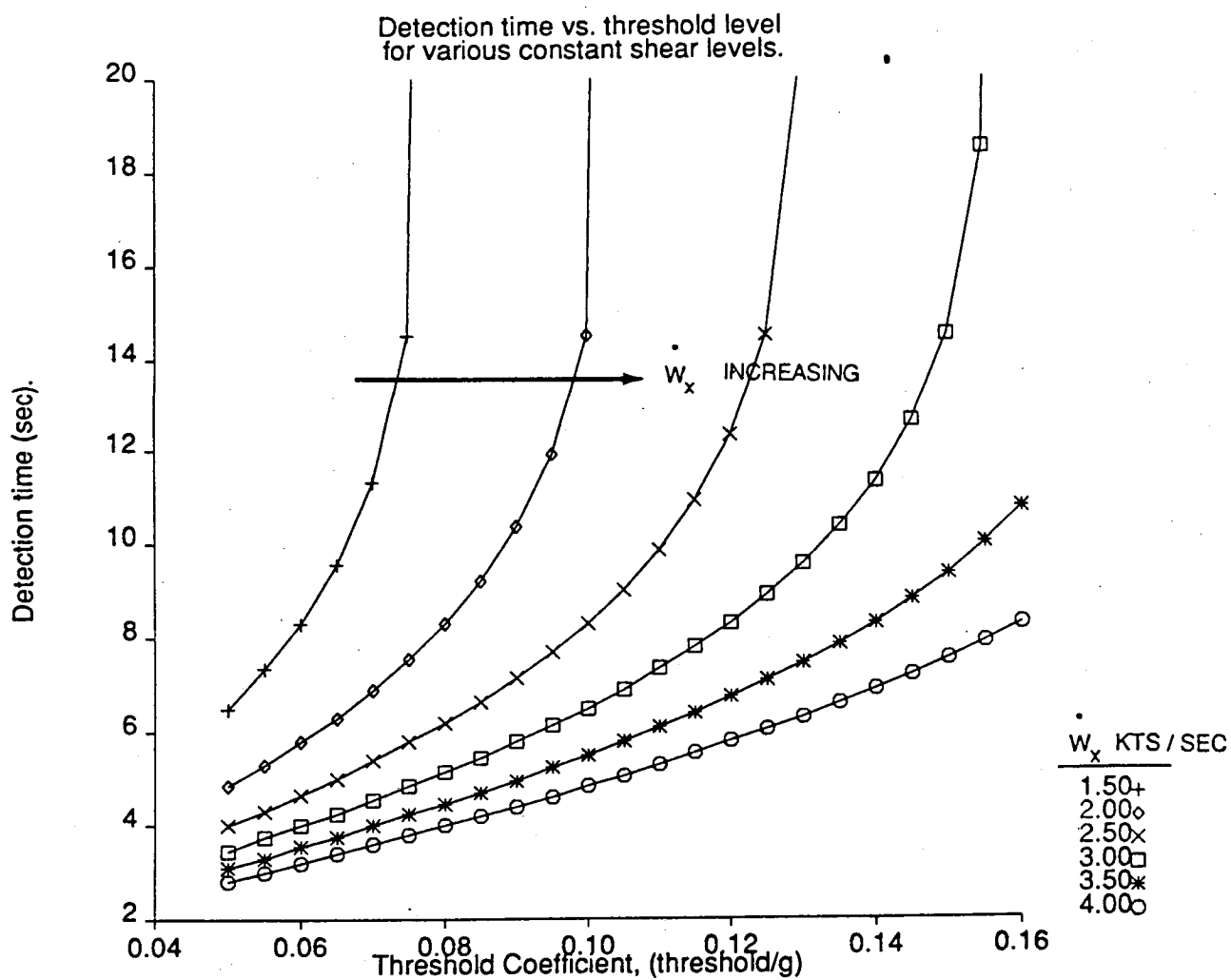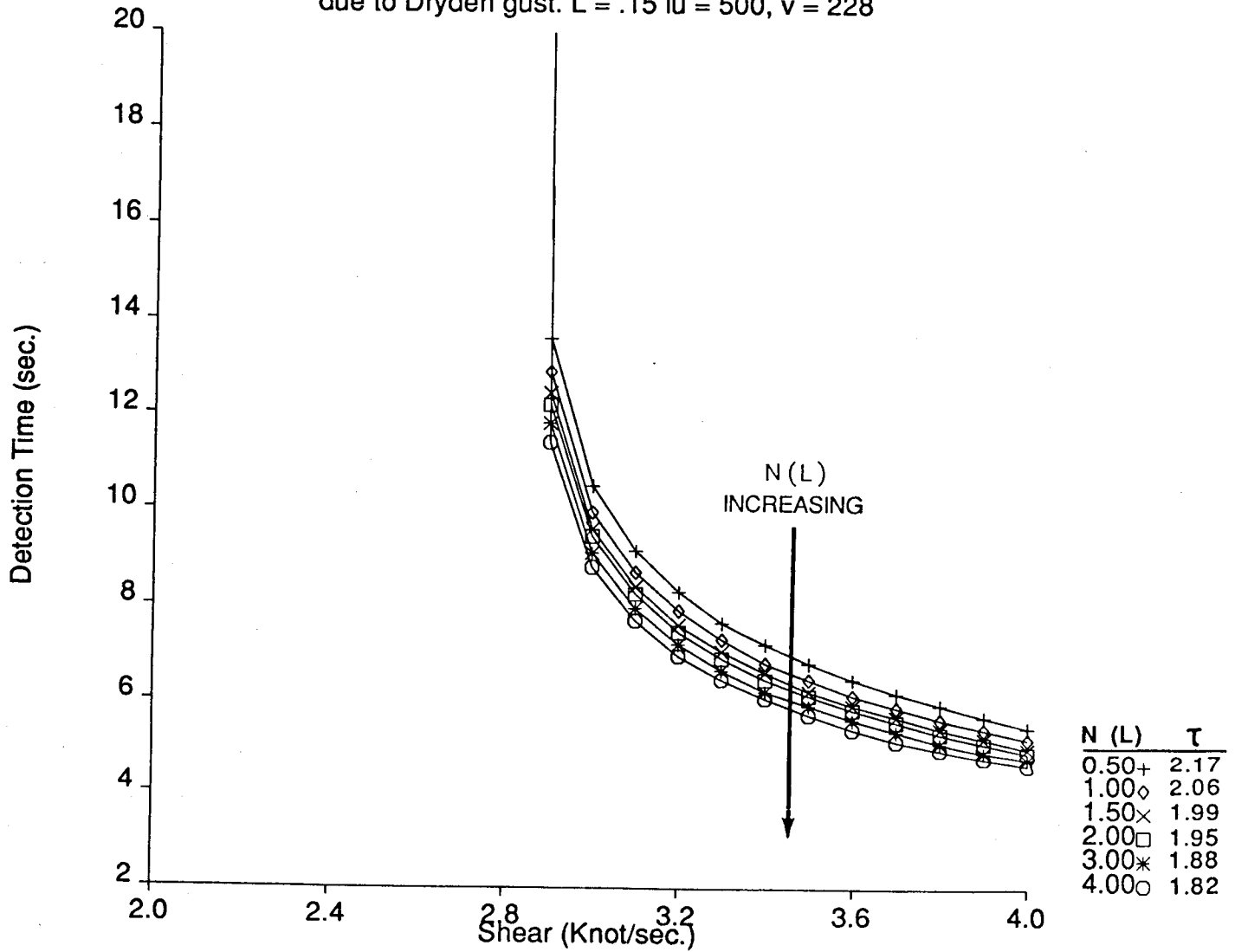
$$H(S) = \frac{\omega n^2 S}{S^2 + 2\xi\omega nS + \omega n^2}$$

$$\xi = .707$$
$$\sigma u = 8 \, FT/SEC$$

Detection time as a function of shear intensity for second order filter having varying nuisance alert rates due to Dryden gust. L = .15 lu = 500, v = 228

N (L)	T
0.50+	2.72
1.00◊	2.59
1.50×	2.50
2.00□	2.44
3.00∗	2.36
4.00○	2.29
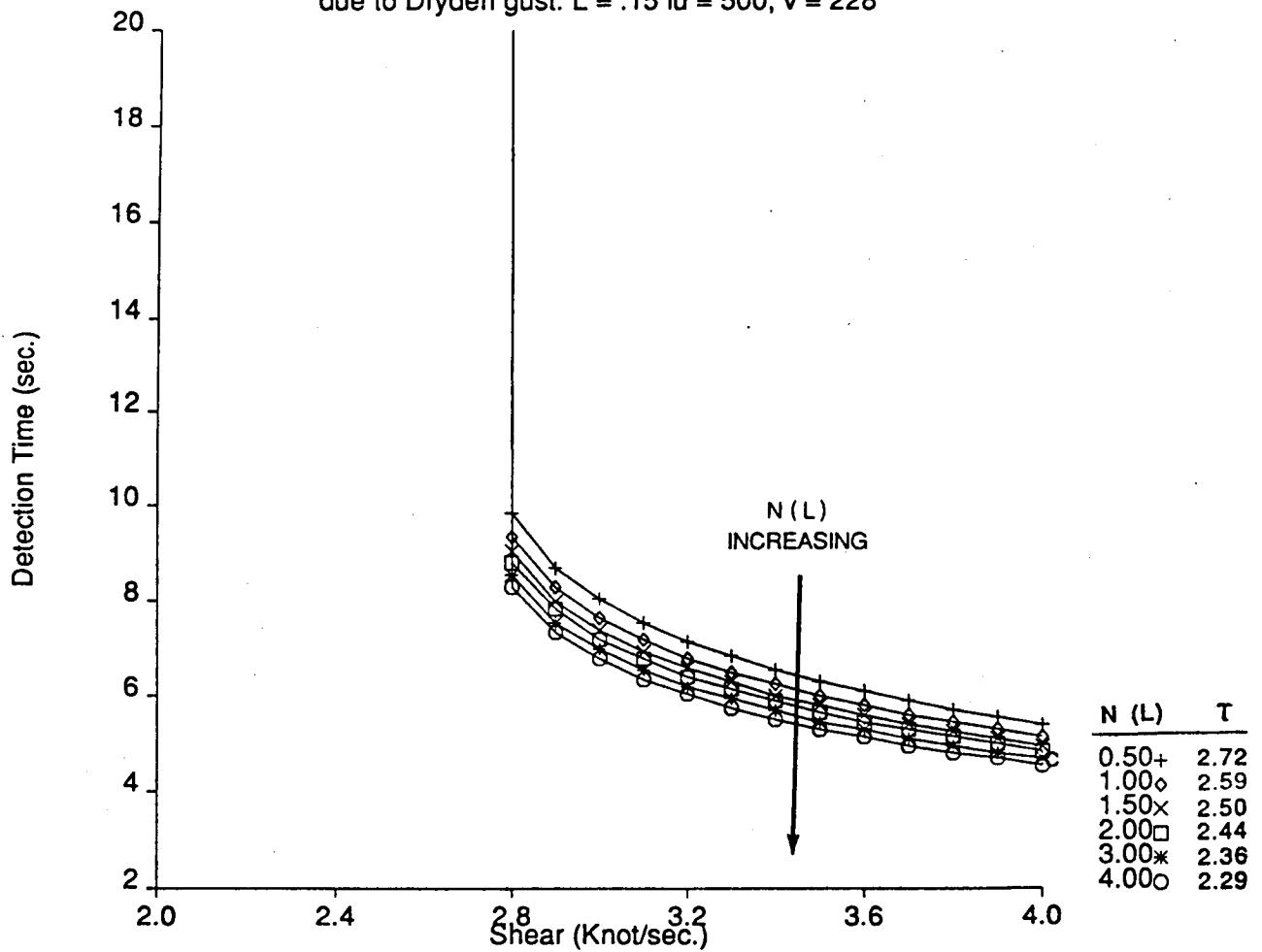
BOEING

$$H(S) = \frac{S}{(\tau S + 1)^2}$$

$$\sigma u = 8 \, \text{FT} / \text{SEC}$$
$$N(L) = 2 / \text{HR}$$

Detection Time vs. Constant Shear for various
coefficient / threshold combinations that satisfy a
gust rejection requirement, N(L) = 2.0 / hr.

L		τ
0.07	+	3.9
0.09	◇	3.2
0.11	×	2.6
0.13	□	2.3
0.15	✳	2.0

BOEING

459
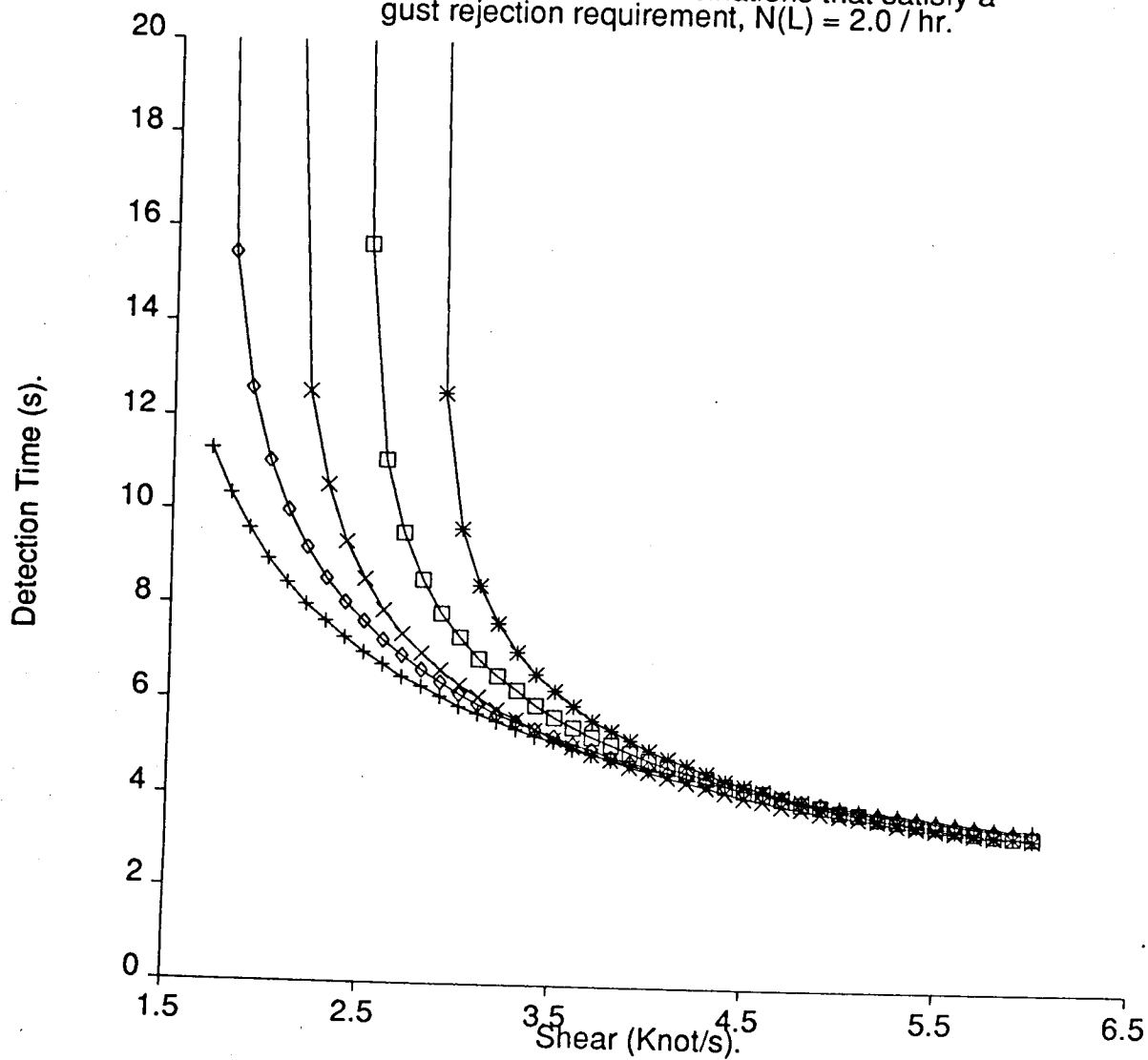
$$H_1 = \frac{s}{(\tau s + 1)}$$

$$H_2 = \frac{s}{(\tau s + 1)^2}$$

$$H_{ab} = H(s) = \frac{s}{(as + 1)(bs + 1)}$$

$$H_x = \frac{W_n^2 \, s}{\left(s^2 + 2\zeta \, W_n \, s + W_n^2\right)}$$

L = THRESHOLD = .15g

σ_u = 8 FT / SEC

N(L) = 2 / HR

1st ORDER τ = 5.6

2nd ORDER $\begin{cases} a = 1.4 \quad b = 2.8 \\ \tau = 2.0 \end{cases}$

2nd ORDER COMPLEX

$\tau = \dfrac{1}{\omega_n} = 2.5$

ξ = .707

TIME1 +
TIME2 ◊
TCMPLX ×
TIMEAB □
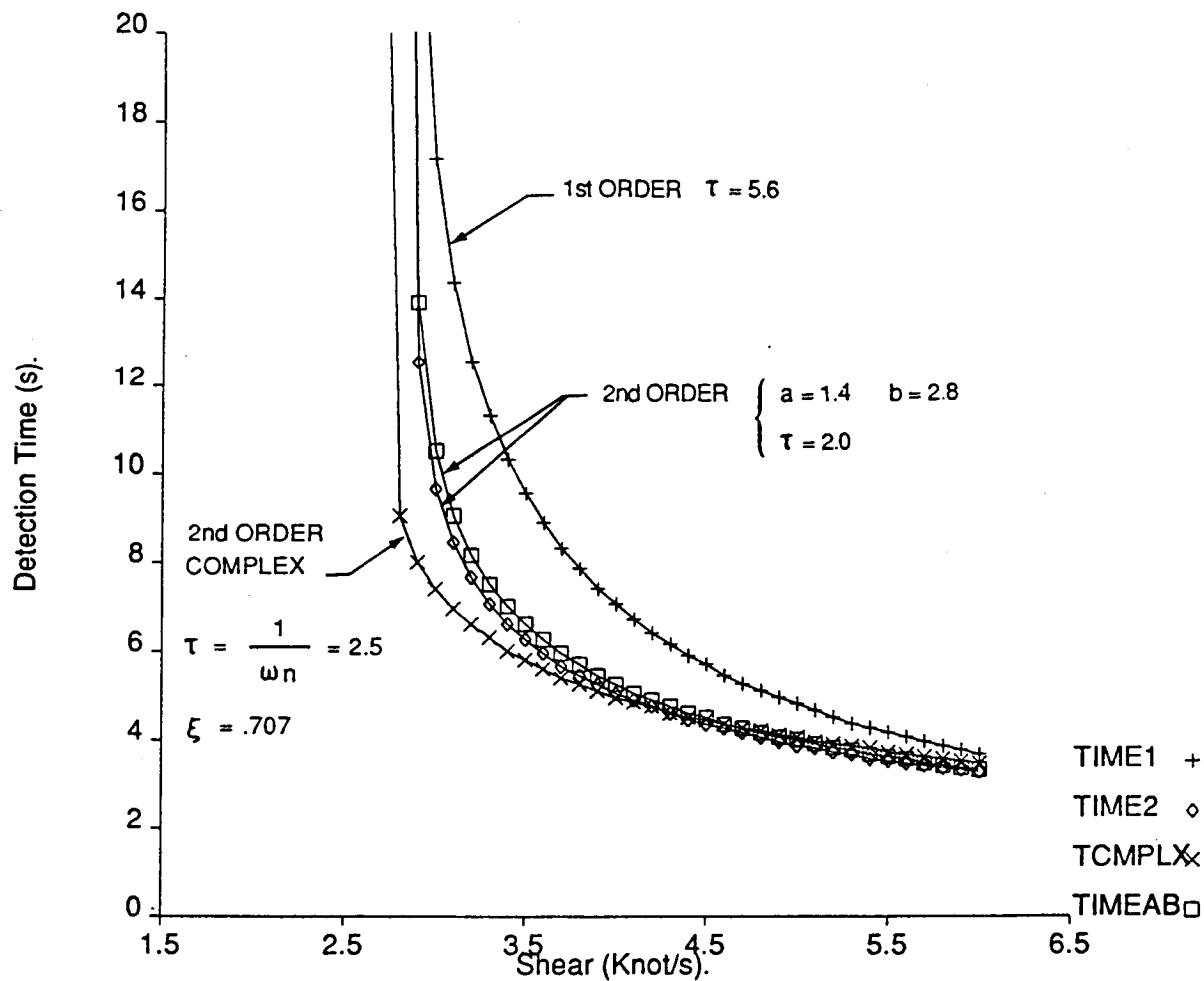
Detection time vs. Constant Shear for first and second order filters.
N(L) = 2.0 crossings per hour.
L = 0.15g

BOEING

460

TIME VERSUS SHEAR

TIME (SEC) vs SHEAR (KTS/SEC)

PENALTY AREA'S BOUNDARIES

NEVER ALERT THRESHOLD

PENALTY AREA

TIME TO LOSE 15 KTS

time15 +

BOEING

461
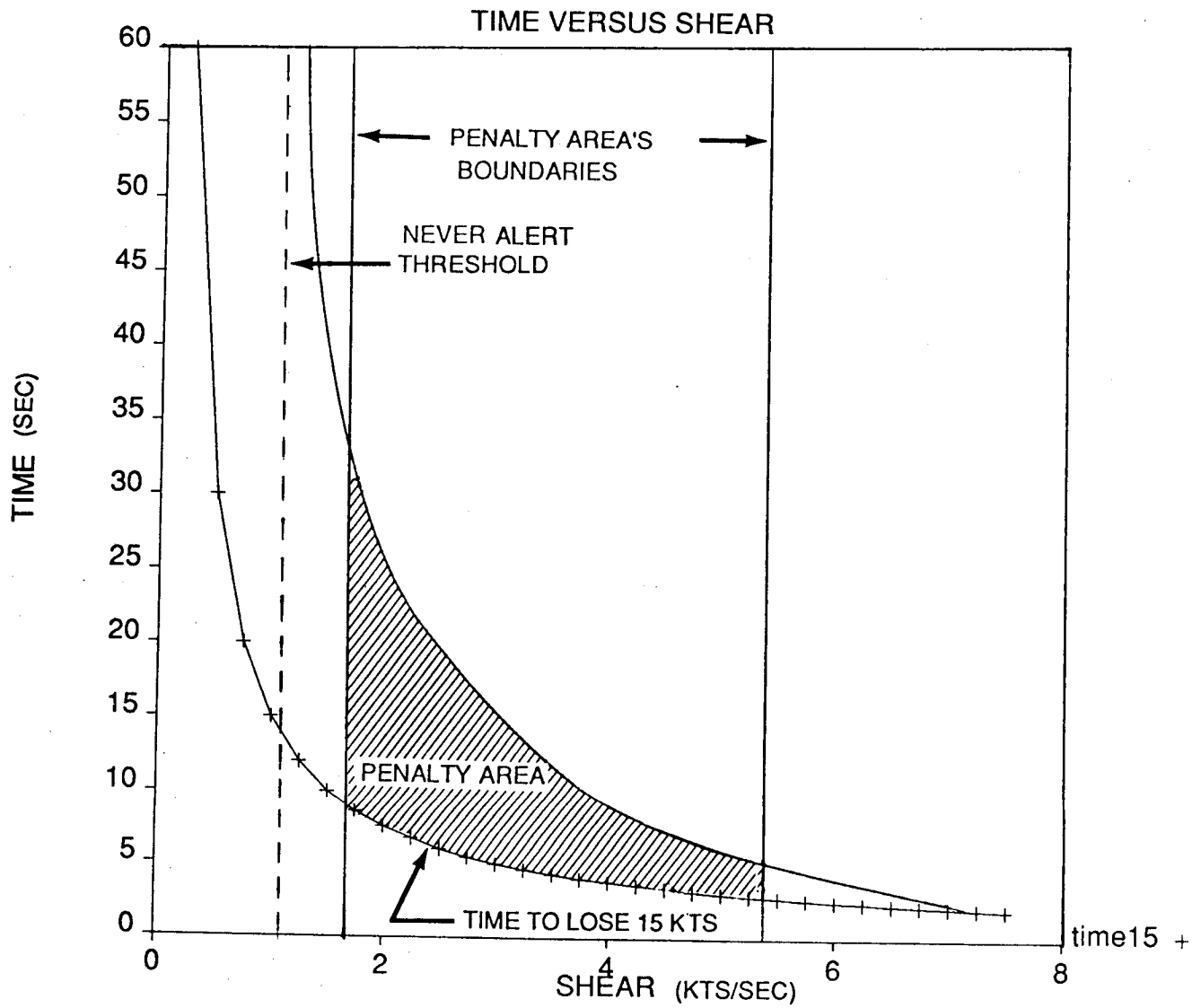
$$H(s) = \frac{\omega_n^2 s}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$
\begin{aligned}
N(L) &= 2 \text{ / HR.} \\
\dot{W}_{xl} &= 2.8 \text{ KTS / SEC.} \\
\dot{W}_{xu} &= 4.0 \text{ KTS / SEC.} \\
L &= .14 \\
\tau &= \frac{1}{\omega_n}
\end{aligned}
$$

Penalty area as a function of filter damping ratio zeta.

$$H(s) = \frac{\omega_n^2 s}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\dot{N}(L) = 2 / \text{HR.}$$
$$\dot{W}_{x\,l} = 2.8 \text{ KTS / SEC.}$$
$$\dot{W}_{x\,u} = 4.0 \text{ KTS / SEC.}$$
$$L = .14$$
$$\tau = \frac{1}{\omega_n}$$

Penalty area as a function of tau.

Tau

FILTER DESIGN METHOD

```
┌─────────────────────────────┐
│   SELECT THE ACCEPTABLE      │◄──────────────────────────┐
│      NUISANCE ALERT          │                           │
│         RATE                 │                           │
└─────────────────────────────┘                           │
               │                                           │
               ▼                                           │
┌─────────────────────────────────────────┐               │
│ SELECT MINIMUM VALUE OF WIND SHEAR       │               │
│   THAT SHOULD TRIGGER AN ALERT.          │               │
│ (WIND SHEAR LEVELS BELOW THIS PRESENT    │               │
│   NO POTENTIAL HAZARD TO AIRPLANE)       │               │
└─────────────────────────────────────────┘               │
               │                                           │
               ▼                                           │
┌─────────────────────────────────────────┐               │
│   SELECT THE WIND SHEAR BOUNDARIES       │               │
│ FOR WHICH THE FASTEST DETECTION TIME     │               │
│             IS DESIRED                   │               │
└─────────────────────────────────────────┘               │
               │                                           │
               ▼                                           │
┌─────────────────────────────────────────┐               │
│   COMPUTE FILTER'S PARAMETERS FOR        │               │
│     THE FASTEST DETECTION TIME           │               │
└─────────────────────────────────────────┘               │
               │                                           │
               ▼                                           │
┌─────────────────────────────┐    NO   ┌──────────────────┐
│   IS DETECTION TIME          │────────►│   MUST ACCEPT    │
│     SATISFACTORY?            │         │ A HIGHER NUISANCE │
│                             │         │   ALERT RATE     │
└─────────────────────────────┘         └──────────────────┘
               │
             YES
               ▼
        ┌─────────────┐
        │    STOP     │
        └─────────────┘
```

BOEING

PROBABILITY DENSITY AND DISTRIBUTION
FOR PEAKS

$$p_p(L) = \frac{1}{N(0)} \frac{dN(L)}{dL}$$

FOR A GAUSSIAN PROCESS:

$$p_P(L) = \frac{L}{\sigma_F^2} \exp\left(-L^2 / 2\sigma_F^2\right) \quad \text{RALEIGH DENSITY FUNCTION}$$

$$P_P(L) = 1 - \exp\left(-L^2 / 2\sigma_F^2\right)$$

PROBABILITY DENSITY FUNCTION FOR
PEAKS OF A GAUSSIAN PROCESS

BOEING

465
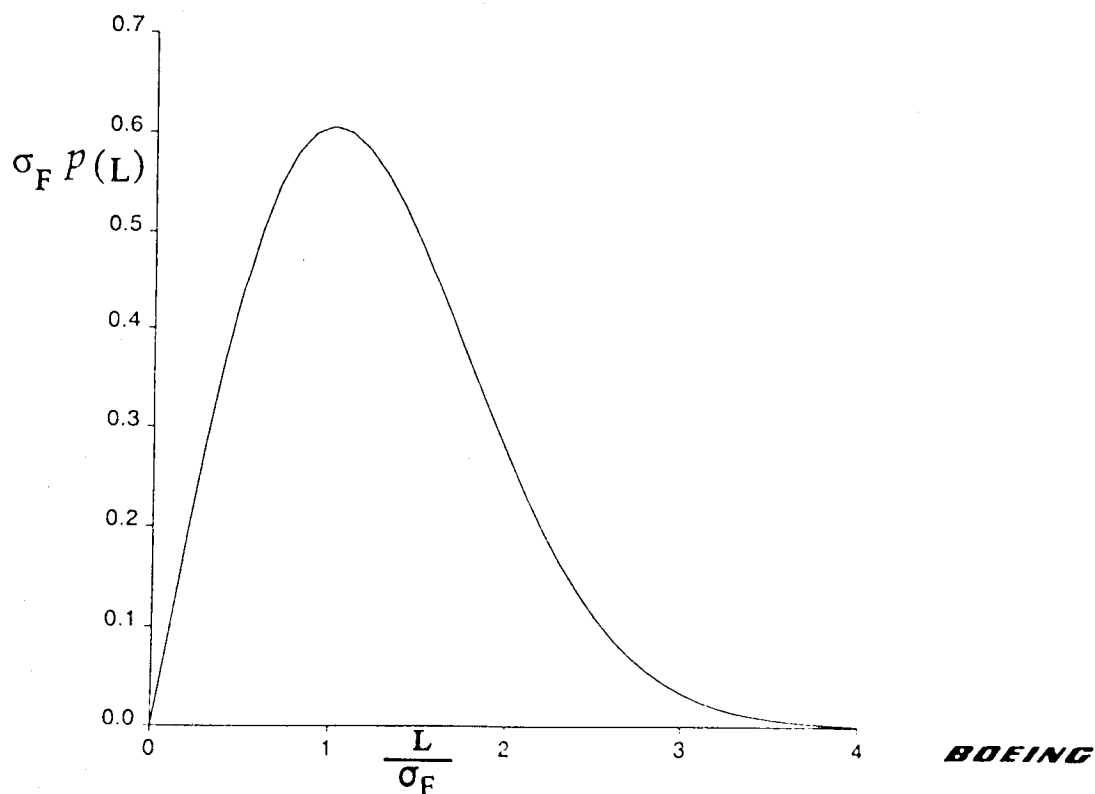
N (L) = AVERAGE TIME DENSITY OF EVENTS

$P_1(L, \Delta T)$ = PROBABILITY OF AN EVENT IN ΔT

$P_2(L, \Delta T)$ = PROBABILITY OF NO EVENT IN ΔT

$P_1 = \Delta T \, N(L)$

$P_2 = 1 - P_1 = 1 - \Delta T \, N(L)$

PROBABILITY OF NO EVENT IN n SUCCESSIVE INTERVALS :

$t_n = n \Delta T$

$$P_2(L, t_n) = \left[1 - \frac{t_n}{n} N(L) \right]^n$$

FOR LARGE n:

$P_2(L, t_n) = \exp(-t_n \, N(L))$

$P_1(L, t_n) = 1 - \exp(-t_n \, N(L))$ PROBABILITY OF AN EVENT IN t_n

FOR A GAUSSIAN PROCESS:

$$P_1(L, t_n) = 1 - \exp\left(-t_n \, N(0) \, \exp\left(-L^2 / 2\sigma_F^2\right)\right)$$

PROBABILITY DISTRIBUTION OF NUISANCE ALERT

BOEING
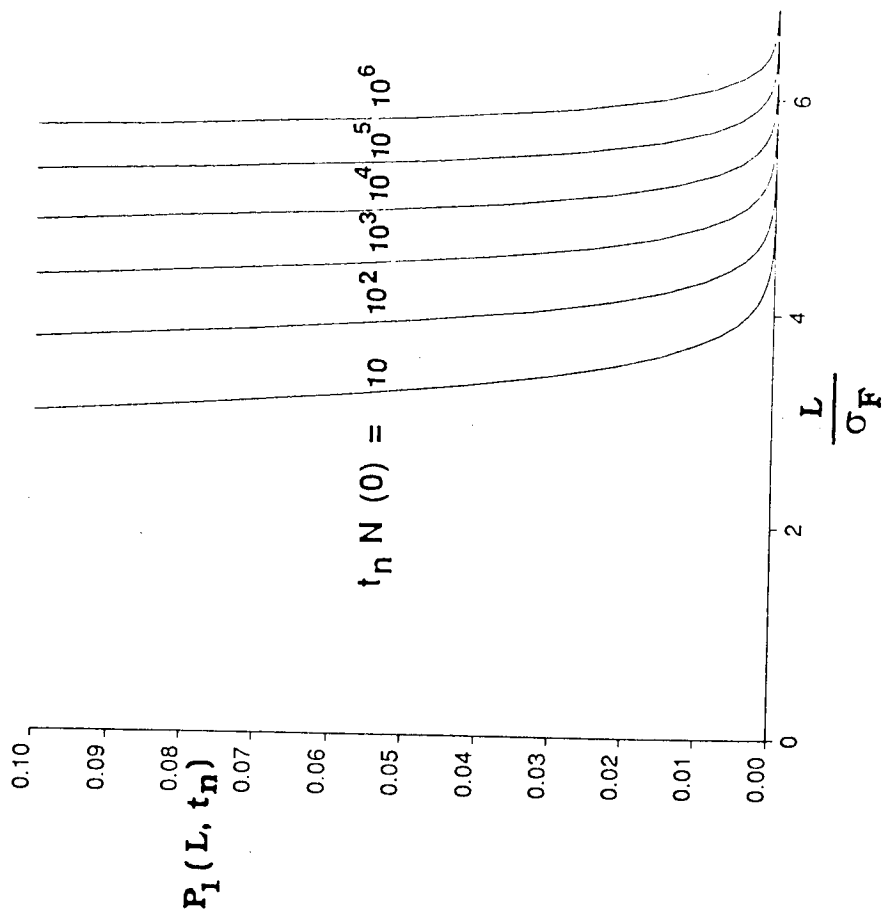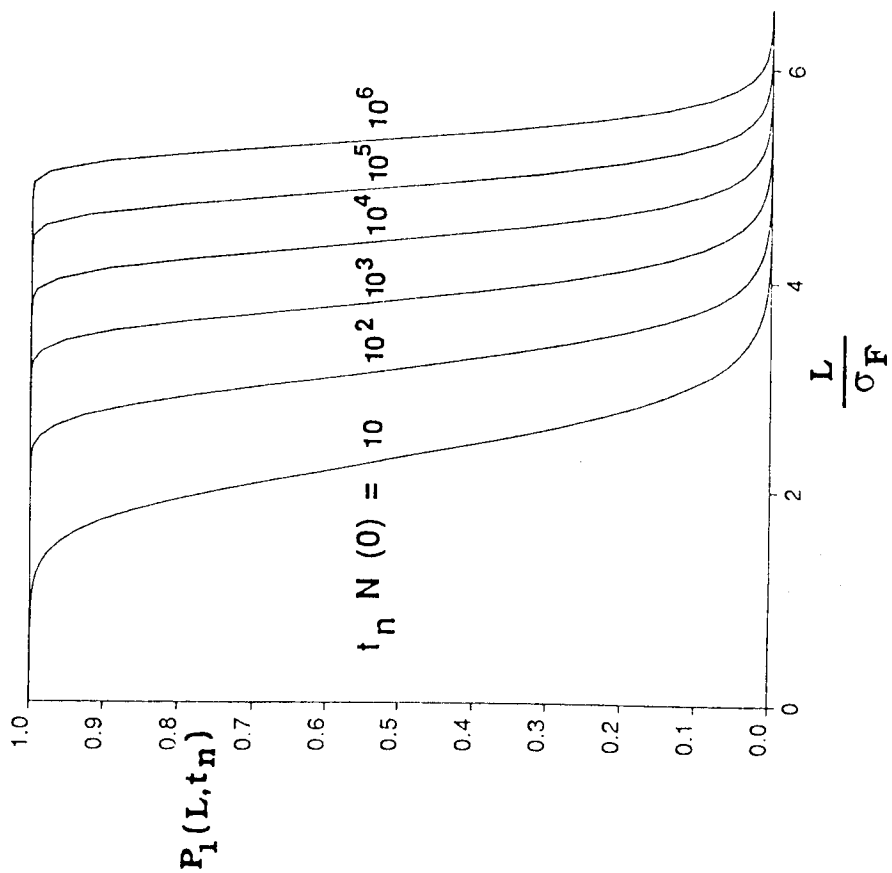
Session II. Airborne–Flight Management

Analysis of Guidance Law Performance Using Personal Computers
J. Rene Barrios, Honeywell/Sperry

NASA

SECOND COMBINED MANUFACTURERS' AND TECHNOLOGY AIRBORNE WINDSHEAR REVIEW MEETING

OCTOBER 18 - 20, 1988
WILLIAMSBURG, VIRGINIA

ANALYSIS OF GUIDANCE LAW PERFORMANCE USING PERSONAL COMPUTERS

PRESENTED BY:

J. RENE' BARRIOS

HONEYWELL INC.
SPERRY COMMERCIAL FLIGHT SYSTEMS GROUP
PHOENIX, ARIZONA

ANALYSIS OF GUIDANCE LAW PERFORMANCE

USING PERSONAL COMPUTERS

ABSTRACT

A POINT MASS, THREE-DEGREE OF FREEDOM MODEL IS PRESENTED AS A BASIC DEVELOPMENT TOOL FOR PC BASED SIMULATION MODELS. THE MODEL HAS BEEN USED IN THE DEVELOPMENT OF GUIDANCE ALGORITHMS AS WELL AS IN OTHER APPLICATIONS SUCH AS PERFORMANCE MANAGEMENT SYSTEMS TO COMPUTE OPTIMAL SPEEDS. ITS LIMITATIONS AND ADVANTAGES ARE DISCUSSED WITH REGARD TO THE WINDSHEAR ENVIROMENT. A METHOD FOR SIMULATING A SIMPLE AUTOPILOT IS EXPLAINED IN DETAIL AND APPLIED IN THE ANALYSIS OF DIFFERENT GUIDANCE LAWS.

THE MODEL

EQUATIONS OF MOTION

IN

RELATIVE WIND AXES

(1) $\dot{V} = G[T.\cos\alpha - D)/W - \sin\gamma] - \dot{W}x.\cos\gamma - \dot{W}z.\sin\gamma$

(2) $\dot{\gamma} = \{G[T.\sin\alpha + L)/W - \cos\gamma] + \dot{W}x.\sin\gamma - \dot{W}z.\cos\gamma\}/V$

(3) $\dot{H} = V.\sin\gamma + Wz$

(4) $\dot{x} = V.\cos\gamma + Wx$

WHERE

V = TRUE AIR SPEED IN KNOTS

T = TOTAL THRUST IN LBS.

D = TOTAL DRAG IN LBS.

L = TOTAL LIFT IN LBS.

W = GROSS WEIGHT IN LBS.

Wx= HOR. WIND COMPONENT IN KNOTS

H = ALTITUDE IN FEET

x = HORIZONTAL DISTANCE IN N. M.

G = GRAVITY ACCEL. IN KNOTS/SEC

α = ANGLE OF ATTACK IN RAD.

γ = FLIGHT PATH ANGLE IN RAD.

Wz= VERT. WIND COMPONENT IN KNOTS

PROGRAM MODULES

MODULE NAME	FUNCTION
MAIN	MAIN LOOP AND SUBROUTINE CALLS
ATMOSPHERE	TEMP, PRES. RATIO & MACH NO.
EQUATIONS OF MOTION	STATE VARIABLES RATES
AERO-COEFFICIENTS	C_L, C_D, LIFT & DRAG
ENGINES	THRUST & ENGINE DYNAMICS
WINDS	WIND & WIND RATES
DETECTION	CAUTION & WARNING FLAGS
INTEGRATION	STATE VARIABLE UPDATE
GUIDANCE (A/P)	CONTROL VARIABLE COMPUTATION
ALPHA LIMIT	PITCH DYNAMICS
PRINT	PRINTS & CREATES FILES
GRAPH	PROVIDES GRAPHIC OUTPUT

THE WIND MODELS

THE CONSTANT SHEAR MODEL

WIND
IN
KNOTS

DISTANCE IN N.M.

THE QUAD-VORTEX MODEL

DISTANCE IN N.M.

WIND
IN
KNOTS

THE GUIDANCE MODULE

CONTROL VARIABLE (ANGLE OF ATTACK)
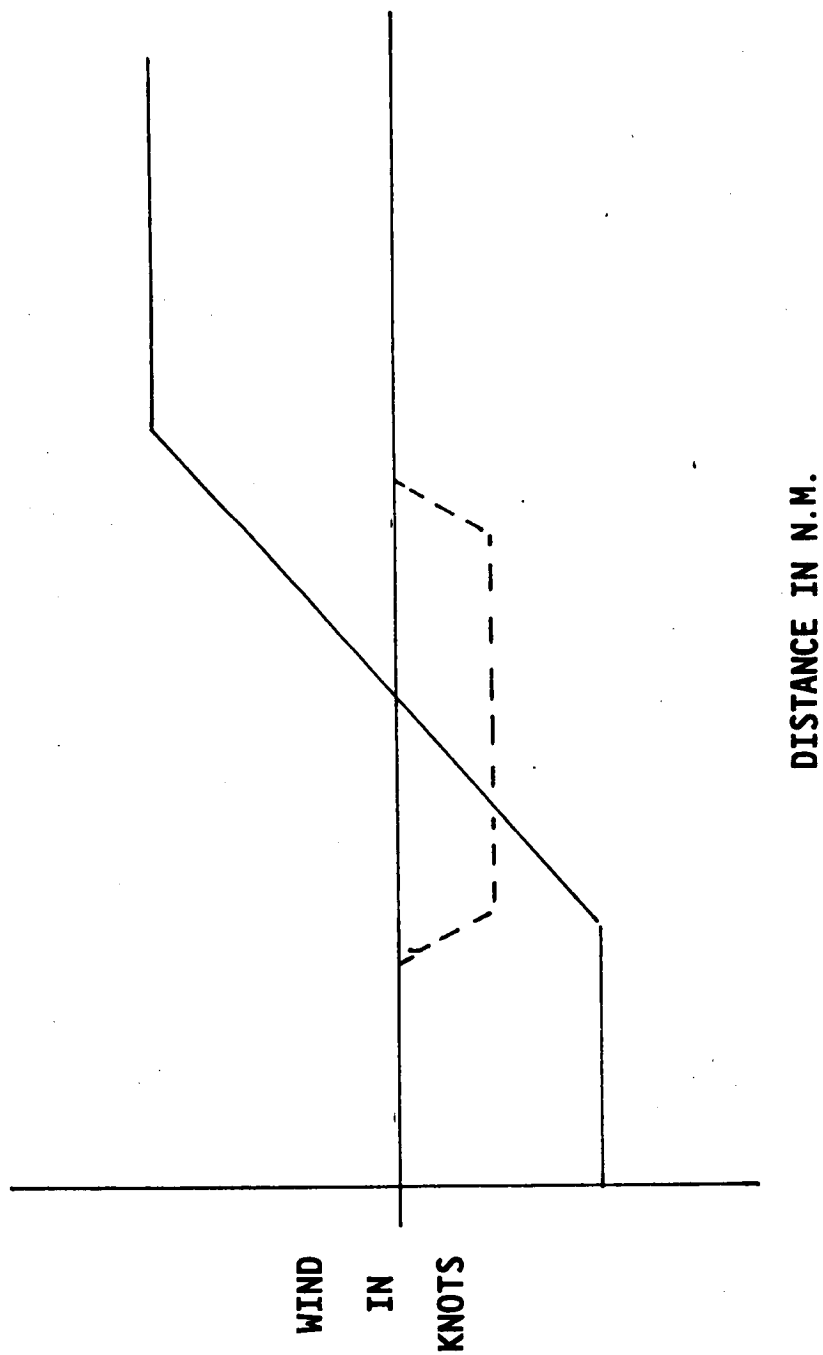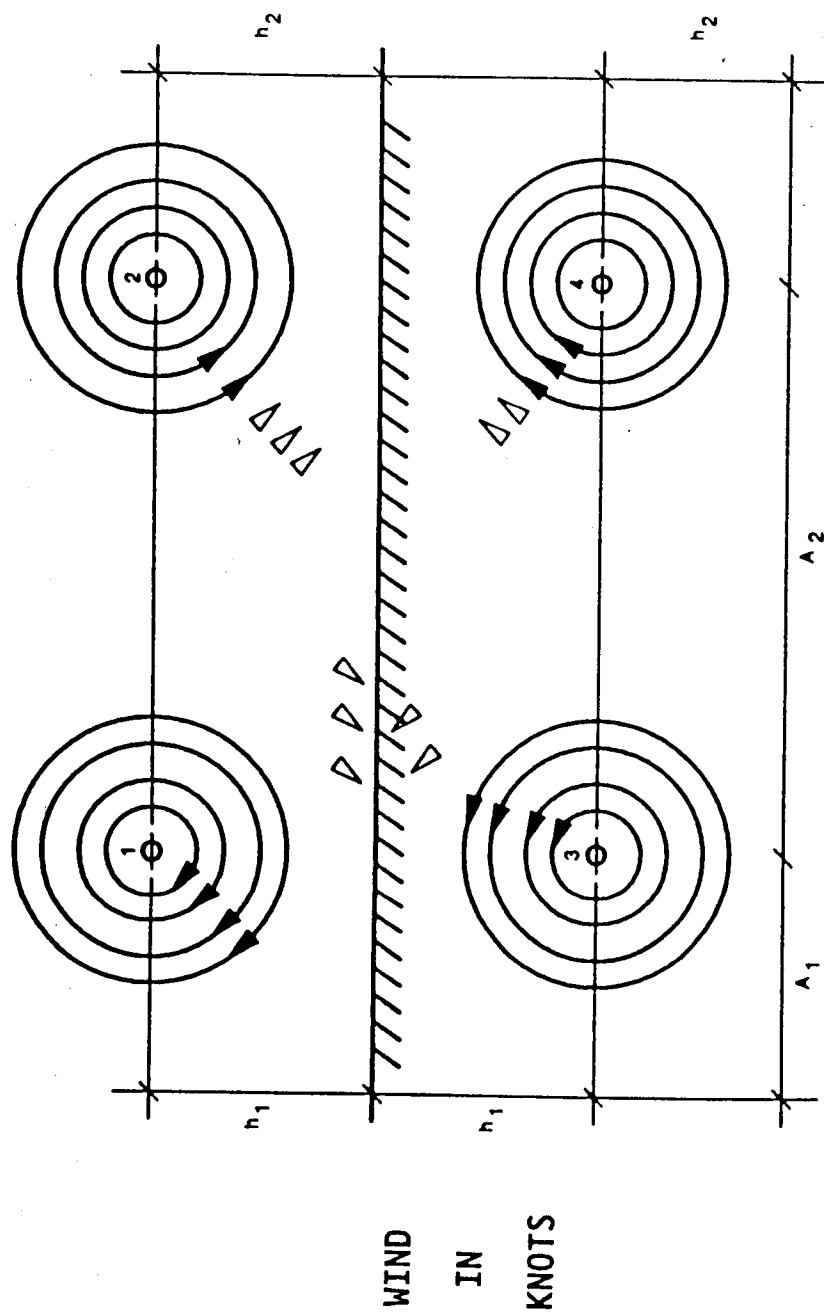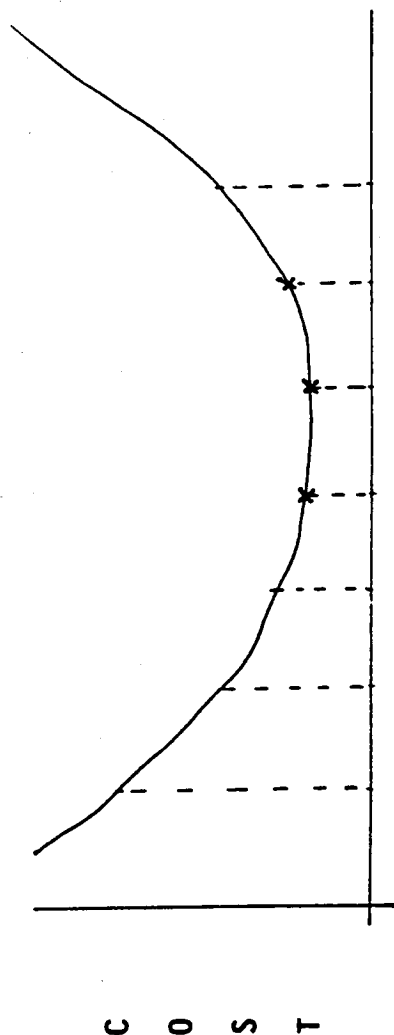
DEFINITION OF COST FUNCTIONS

1) 1.1*VSTALL $COST = (V + \dot{V}*DT - 1.1*VS)^2$

2) STICK SHAKER $COST = (ALPHA - ASTKR)^2$

3) $AX = 0$ $COST = (\dot{V} - V*\dot{GM}*GM + WX)^2$

4) 15 DEG. PITCH $COST = (GM + \dot{GM}*DT + ALPHA - 15)^2$

5) HONEYWELL'S $COST = (GM + \dot{GM}*DT - GMR)^2$

WHERE

GM = FLIGHT PATH ANGLE W/RT AIR MASS

GI = INERTIAL FLIGHT PATH ANGLE

$GMR = GI*(1 + WX/V) - WZ/V$

PC MODEL APPLICATIONS

* PERFORMANCE MANAGEMENT SYSTEMS

  - DETERMINATION OF OPTIMAL SPEEDS FOR MINIMUM COST TRAJECTORIES

  - DETERMINATION OF OPTIMUM ALTITUDE FOR SHORT RANGE FLIGHTS

* WINDSHEAR GUIDANCE ALGORITHMS

  - DEVELOPMENT OF THEORETICAL GUIDANCE LAWS USING DIFFERENT CONCEPTS SUCH
    AS GAMMA REFERENCE, ENERGY ETC.

  - DEVELOPMENT OF NUMERICAL ALGORITHMS FOR THE SOLUTION OF THE "GAMMA
    REFERENCE GUIDANCE AS A MAYER PROBLEM IN THE CALCULUS OF VARIATIONS".

737 WINDSHEAR GUIDANCE

SHEAR: 15S @ 5KT/S, DNBURST: 13S @ 7KT

ALTITUDE IN FEET (Thousands)

ELAPSED TIME IN SECONDS   Ah=0

1 1.1XVs   2 SS   3   4 15'   5 Honeywell

737 WINDSHEAR GUIDANCE

SHEAR: 20S @ 5KT/S, DNBURST: 18S @ 7KT

ALTITUDE IN FEET

ELAPSED TIME IN SECONDS

| _1_ 1.1XVs | _2_ SS | _3_ Ah=0 | _4_ 15' | _5_ Honeywell |
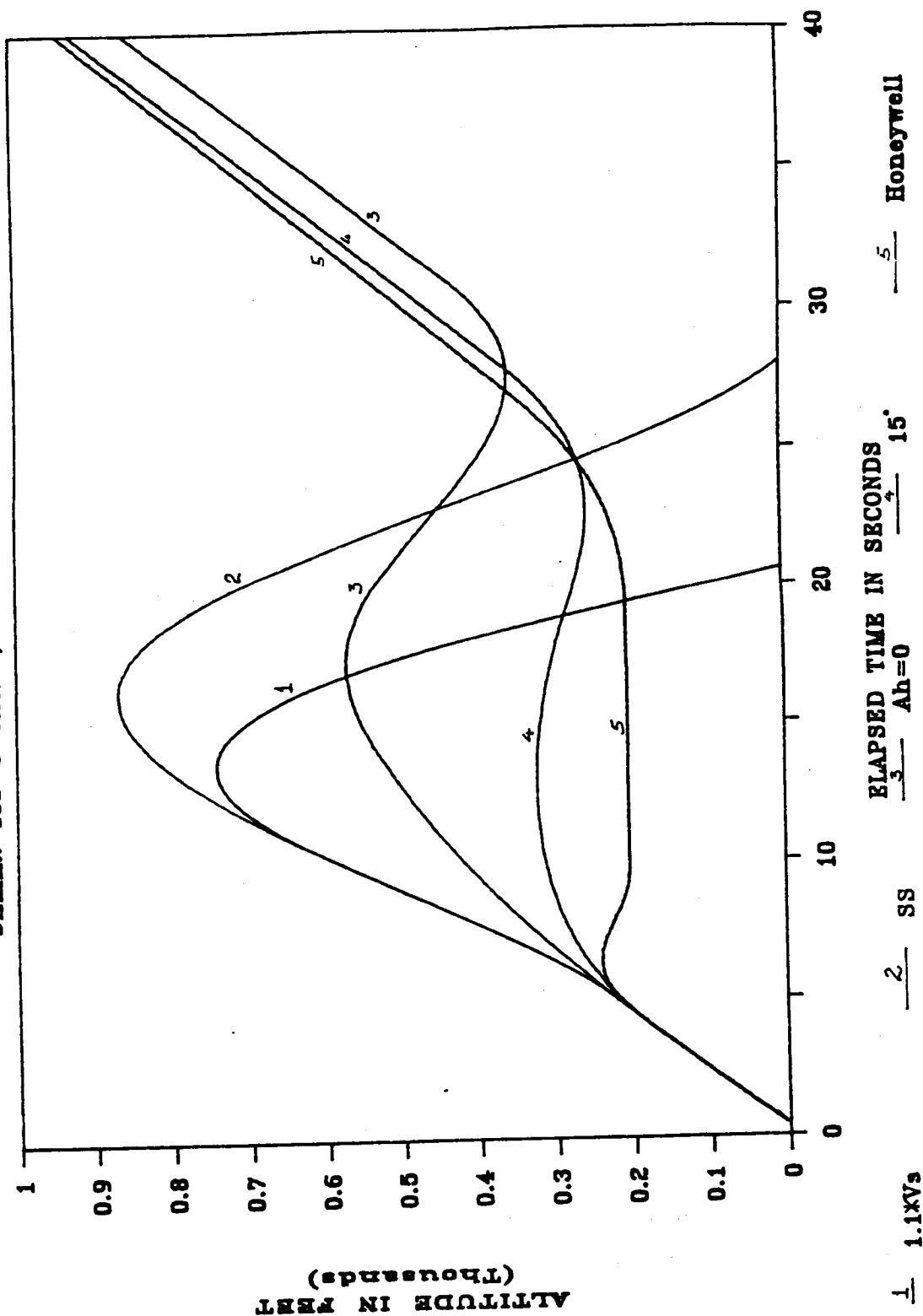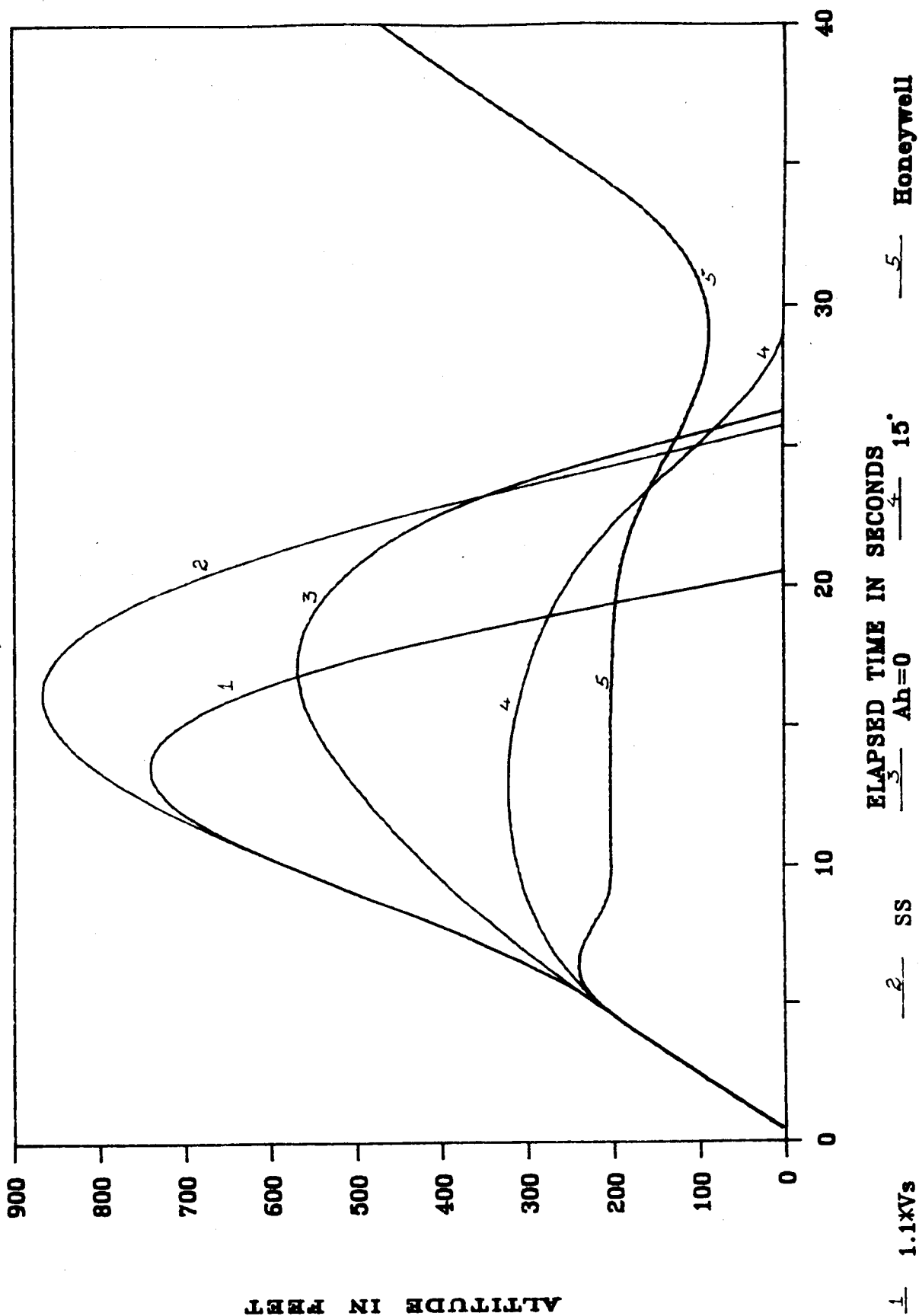
L-1011 WINDSHEAR GUIDANCE

SHEAR: 9S @ 4KT/S, DNBURST: 6S @ 7KT

482
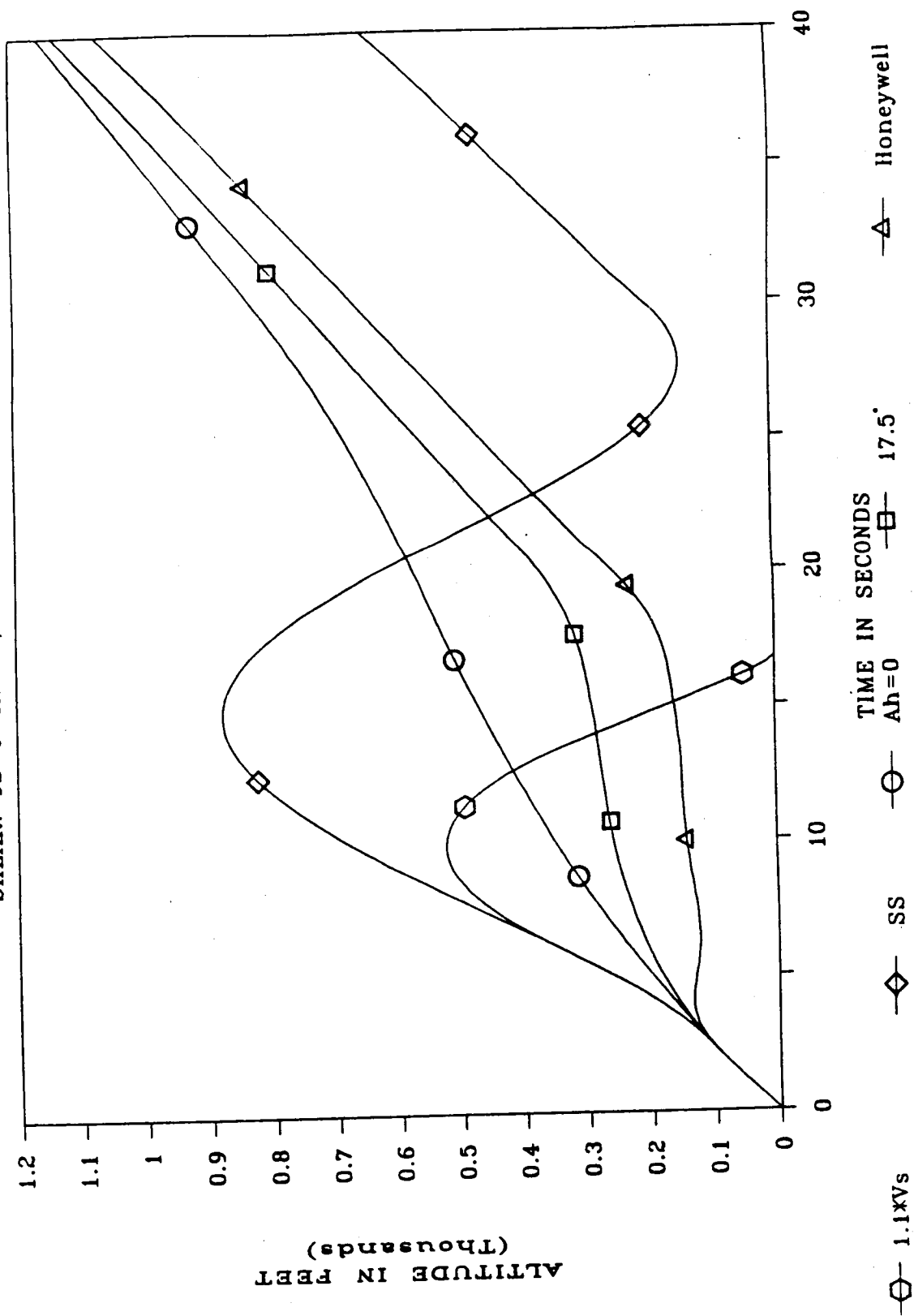
L-1011 WINDSHEAR GUIDANCE

SHEAR: 24S @ 4KT/S, DNBURST: 21S @ 7KT

ALTITUDE IN FEET

TIME IN SECONDS

◇ — SS   ○ — Ah=0   □ — 17.5'   △ — Honeywell

⬡ — 1.1xVs

483
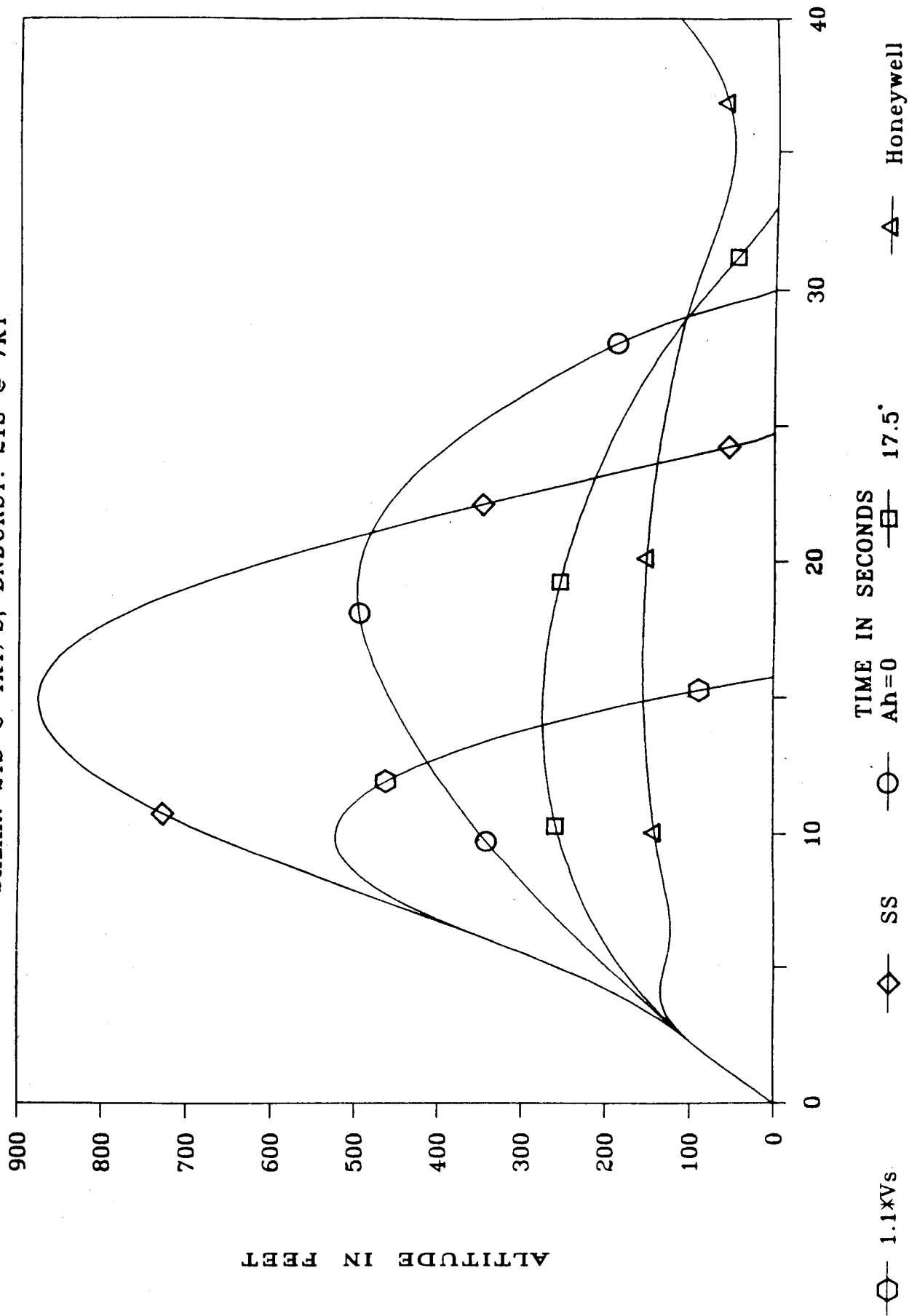
Future Enhancements

On

PC-Based Models

* Six Degrees of Freedom

* Control Surface Dynamics

* 3-D Wind Models

* Real Time I/O

* Takeoff/Roll Dynamics

* Instrument Error Models

Session II. Airborne–Flight Management

Crew Interface with Wind Shear Systems
Dave Carbaugh, Boeing

Crew Interface With Windshear Systems

Dave Carbaugh

The Boeing Commercial Airplane Company

Flight Deck Research

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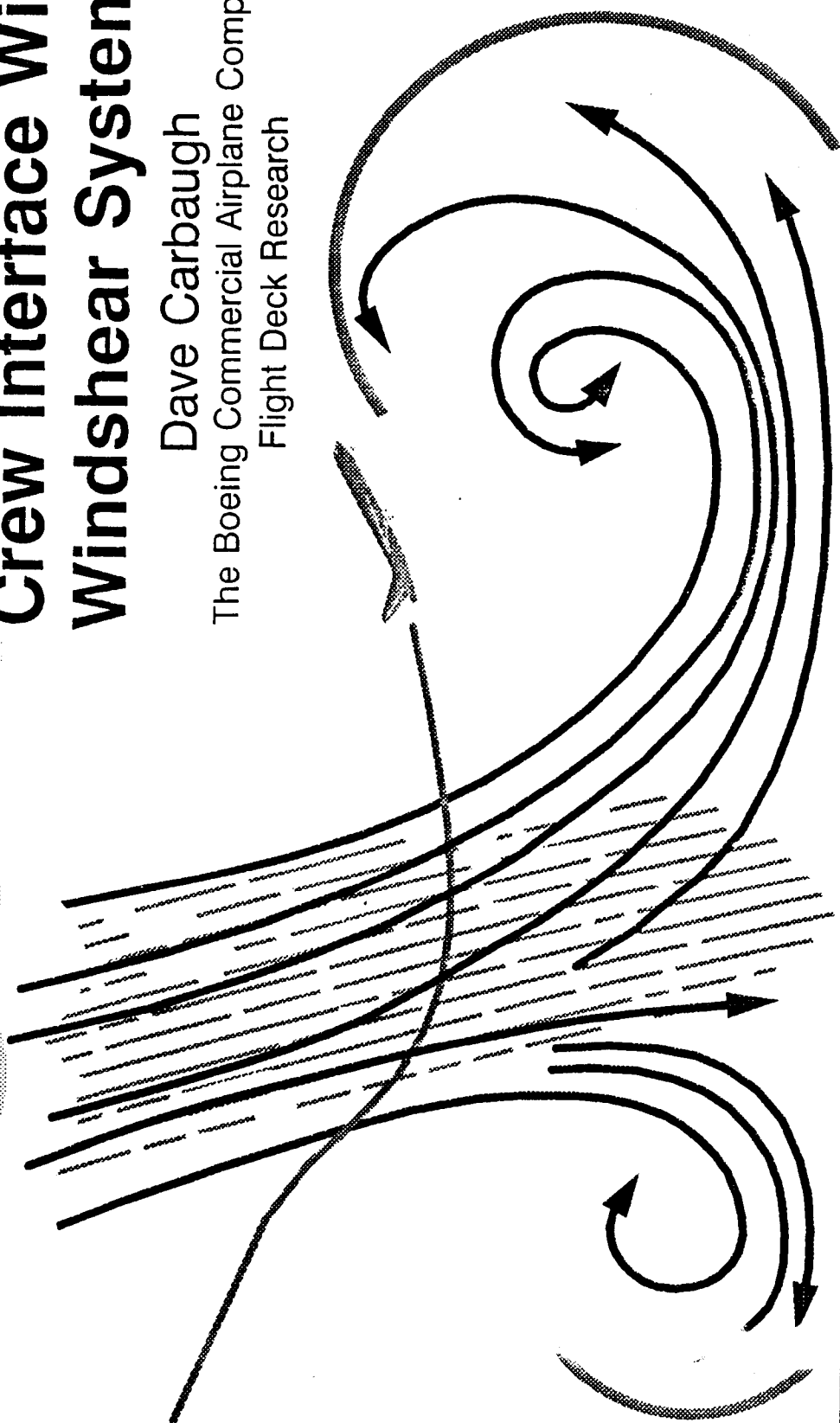
Crew Interface With Windshear Systems

- Overview of Project
- Research Issues Document and Database
- Alerting Simulation
- Future Efforts

Flight Deck Research Involvement NAS1-18027 Task 9 Windshear Studies

- Crew interface with windshear systems

  Human factors approach to the integration and application of lookahead and reactive windshear detection systems as they interface with flightcrews

- Goal

  To provide industry with a database of crew information requirements, crew performance requirements, and display design guidelines for use in development and manufacturing of certifiable airborne windshear systems

Objectives

- Establish information requirements needed by flightcrews to avoid hazardous windshear

- Develop candidate formats of how that information should be presented to the flightcrew

- Develop operational and functional requirements for integration of reactive and predictive sensor information

- Develop the procedures and criteria needed to demonstrate crew performance using windshear systems

- Evaluate candidate crew interface concepts

B1259.08

Crew Interface With Windshear Systems Program Approach

B 1259.09
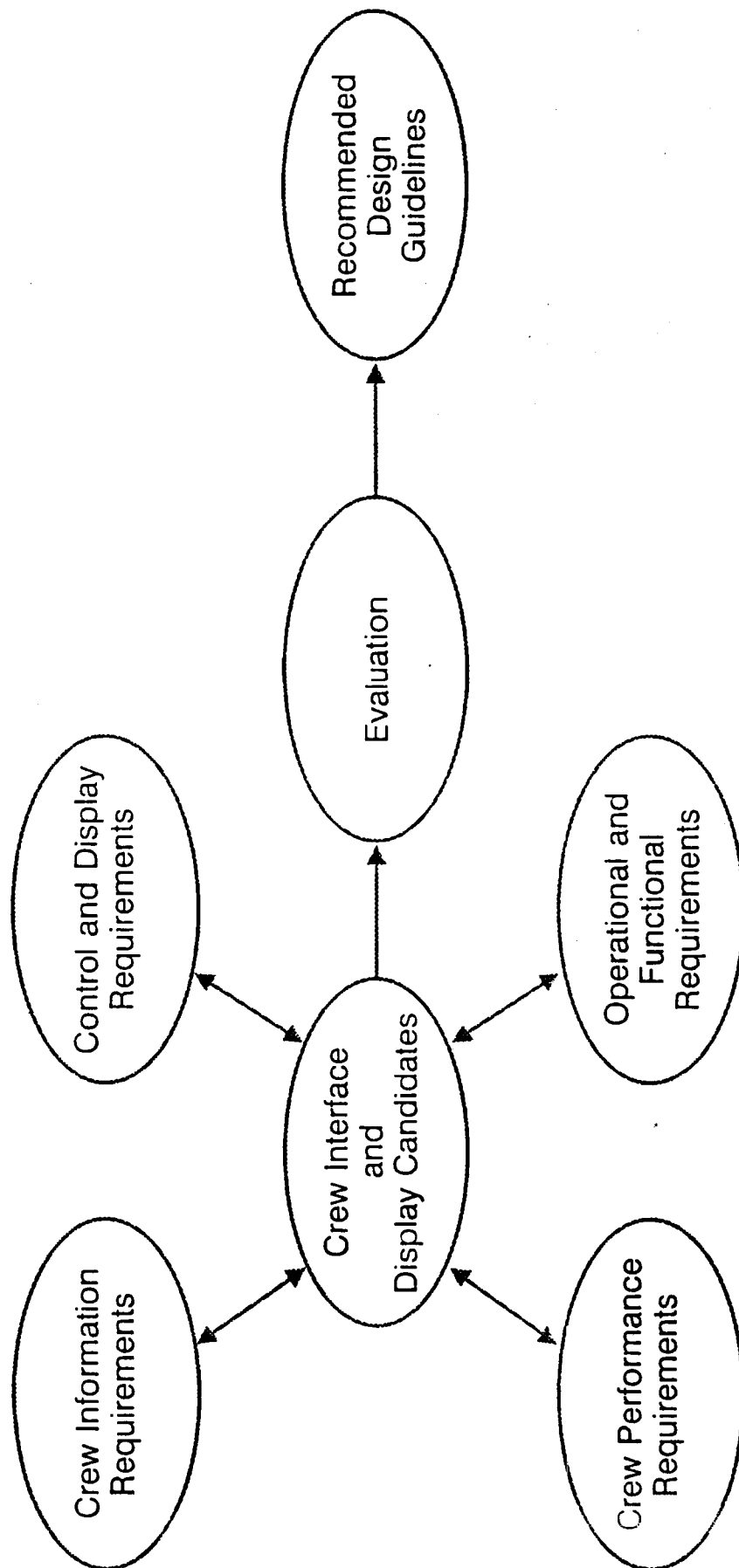
Accomplishments

● 4-year program plan - approved by NASA

● Crew interface issues identified - survey of airlines, technologists, manufacturers, FAA, NASA, SAE S-7

● Database of crew interface issues - maintained at Boeing

● Lookahead alerting simulation - 737-300 on approach, Boeing first to use new NASA windshear model in simulator

Follow-on Efforts

● Lookahead alerting display development

● Lookahead alerting simulation - takeoff situations

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Issues Document

- Identified crew interface issues

- Prioritized according to implementation impact

- Developed the data base

Windshear Issues Document

- Purpose

  - Priority of research

  - Identify issues

- Future

  - Provide ready-access

  - Information exchange

Issues Document Limitations

- Forward-look orientated

- No involvement in FAA regulatory changes

- Not sensor specific

- Reactive devices are incorporated as part of system

- Involve with man-machine interface

- Limit ground-based involvement

Prioritized According to Implementation Impact

- Critical
  - Issue resolution required prior to industry-wide implementation
  - If left unresolved
    1. Critically limits the operational capabilities of the system
    2. Critically affects pilot confidence in the system
    3. Critically degrades flight safety in certain windshear situations

- Serious
  - Should be resolved prior to industry-wide implementation
  - A serious issue, if left unresolved
    1. Limits the operational capability of the system
    2. Affects pilot confidence in the system
    3. Degrades flight safety in certain windshear situations

E1259.04 R2

Prioritized According to Implementation Impact (Continued)

- Desirable

  - A resolution of an issue could be expected to improve the physical and/or operational man-machine interface

- If left unresolved

    1. Could limit the operational capability of the system

    2. Could affect pilot confidence in the system

    3. Could degrade flight safety in certain windshear situations

Windshear Detection Survey
Top Five Critical Items

E1259.06

Developed the Data Base

- In use today

- IBM PC microcomputer with RBase System V software

- 29 issues

- Benefits

  - Report generation capability

  - Reduced time to conduct research

  - Results of research easily accessible

Windshear Detection Issues Identification

Issue Code: A20.000   Related Codes: A44.000

Entry Date: 02/12/88   Retrieval Date: -0-   Update: -0-

Name of Issue:

3D View of the Hazard

Description:

Avoidance of the microburst windshear using look-ahead devices should consider the 3D aspects of the phenomenon. The display of windshear situations may be presented in 3D or simulated 3D electronic cockpit displays.

Requirements, Recommended or Implemented Approach:

Evaluate various "3D" windshear displays to determine the effects of these displays on pilot performance in avoiding the windshear hazard.

(Y) Current Activity or (-0) Conclusions:

E1259.08 R2

Alerting Simulation

- Simulate forward-look alerting

- Provide range of possible pilot use strategies

- Assist in categorizing the alerts

Look-ahead Alerting Simulation

- NASA windshear model

- 737-300 with EFIS

- Reactive system used

- Simulated look-ahead time critical alert

- Boeing pilots evaluation

NASA Windshear Model

- Fred Procter's windshear model

- Wet microburst at 11.5 min

- Large microburst

- 40,000 wind vectors programmed

- Data to include F-factor

737-300 With EFIS

- Maximum landing weight

- Full EFIS instrumentation used

- Limitations

- Fixed-based with visual

Reactive System Used

- Boeing Sunstrand system

- Visual/aural alerting method

- Easily recognized

- Missed encounters

Simulated Look-ahead Time Critical Alert

- Visual/aural alerting methods

- Procedural methods

- Alert timing variation

- Pilot acceptance/suggestions

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Boeing Pilots Evaluation/ Comments/Conclusions

- Windshear model lacks turbulence/roll transients

- Windshear model is severe

- Look-ahead warning

  1. Easily distinguishable

  2. Prompted immediate action

  3. EADI integration favored

- Pilot favored normal go-around procedures

- Look-ahead alerting timing not related to maximum F-factor encountered

- Look-ahead alerts with less than 11 sec advanced warning to reactive alerts are too late

- Time critical alerts issued prior to 36 sec until reactive alert are too early

- Information available prior to alerting adds real benefits in being prepared

Conclusions and Follow-on Tasks

- Limited study

- Pilot response to alerting

- Integration of alerting and procedures

- Preview information impact

- Nuisance factors

- Range of alerting

Follow-on Tasks

- "Masked simulation"

- Response time
- Shear rate variances

- Preview information methods and displays

- PC generated
- Simulator capable

- Continued lookahead simulation

- Takeoff problems
- Aircraft types

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Session II. Airborne–Flight Management

An Expert System for Wind Shear Avoidance
Robert Stengel and Alex Stratton, Princeton University

An EXPERT SYSTEM for
WIND SHEAR AVOIDANCE

Robert Stengel and Alex Stratton

PRINCETON UNIVERSITY
Department of
Mechanical and Aerospace Engineering
Princeton, NJ

Overview and Background
FAA Windshear Training Aid
Expert Systems
WindShear Safety Advisor

AN EXPERT SYSTEM FOR WIND SHEAR AVOIDANCE

Robert F. Stengel and D. Alexander Stratton

PRINCETON UNIVERSITY
Department of Mechanical and Aerospace Engineering
Princeton, New Jersey 08544

ABSTRACT

Flight in strong wind shears, especially microbursts, poses a unique and severe hazard to aircraft. The disturbance caused by the wind field may literally exceed the performance character- istics of the aircraft, making safe transit impossible even with optimal guidance and control strategies. An unusual degree of piloting skill may be required to successfully elude danger. Only the best pilots may be able to cope with strong wind shears, but even they may be unable to safely penetrate extreme wind shears. Nevertheless, planes fly in moderate wind shear all the time; pilots learn to handle crosswinds, gustiness, and moderate frontal activity. The problem is that microbursts are random, rare phenomena: pilots do not develop the needed skills for coping with wind shear through normal experience. The typical pilot is likely to be confronted with a life-threatening wind shear only once or twice in an entire flying career; hence, it is unlikely that he or she can learn all the important signs of wind shear and maintain a high level of proficiency in the proper con- trol procedures.

On-board computation provides an excellent opportunity to assist the pilot in surviving encounters with severe wind shears, but the logic that must be executed in real time is complex and must have sufficient inputs for framing decisions about appropri- ate control actions. The computer program(s) and hardware to perform this task must have attributes of expert systems and con- trol systems, they must account for the limitations of aircraft performance, and they must operate in real time. At least as important as its technical specifications, the on-board system must provide a satisfactory interface with the flight crew, which bears the ultimate responsibility for assuring safety. This means not only that the system must deduce near-optimal strateg- ies and tactics for emergency situations but that it must dis- tinguish between truly hazardous conditions and the more likely alternatives associated with normal aircraft operations.

A program to investigate ways of protecting against the adverse effects of wind shear during aircraft takeoffs and land- ings has begun, with current emphasis on developing an expert system for wind shear avoidance. Our principal objectives are to

develop methods for assessing the likelihood of wind shear encounter (based on real-time information in the cockpit), for deciding what flight path to pursue (e.g., takeoff abort, landing go-around, or normal climbout or glide slope), and for using the aircraft's full potential for combating wind shear. This study requires the definition of both deterministic and statistical techniques for fusing internal and external information, for making "go/no-go" decisions, and for generating commands to the aircraft's autopilot and flight directors for both automatic and manually controlled flight.

The expert system for pilot aiding is based on the results of the FAA Windshear Training Aids Program, a two-volume manual that presents an overview, pilot guide, training program, and substantiating data provides guidelines for this initial development. The WindShear Safety Advisor expert system currently contains over 140 rules and is coded in the LISP programming language for implementation on a Symbolics 3670 LISP Machine.

BACKGROUND

Flight in strong wind shears, especially microbursts, poses a unique and severe hazard to aircraft. The disturbance caused by the wind field may literally exceed the performance characteristics of the aircraft, making safe transit impossible even with optimal guidance and control strategies. An unusual degree of piloting skill may be required to successfully elude danger. Nevertheless, planes fly in moderate wind shear all the time; pilots learn to handle crosswinds, gustiness, and moderate frontal activity. The problem is that microbursts are random, rare phenomena; pilots do not develop the needed skills for coping with wind shear through normal experience. The typical pilot is likely to be confronted with a life-threatening wind shear only once or twice during an entire flying career; hence, it is unlikely that he or she can learn all the important signs of wind shear and maintain a high level of proficiency in the proper control procedures.

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A program to investigate ways of protecting against wind shear has begun at Princeton University, with current emphasis on developing an expert system for wind shear avoidance. This program is sponsored by the NASA Langley Research Center under Grant No. NAG-1-384. Our principal objectives are to develop methods for assessing the likelihood of wind shear encounter (based on real-time information in the cockpit), for deciding what flight path to pursue (e.g., abort, go-around, normal climbout, or glide slope), and for using the aircraft's full potential to combat wind shear. This study requires the definition of deterministic and statistical techniques for fusing internal and external information, for making "go/no-go" decisions, and for generating commands to the aircraft's autopilot and flight directors in automatic and manually controlled flight.

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BACKGROUND

Hazards of Low-Altitude Wind Shear

Difficulty of Maintaining Pilot Proficiency

Proper Decision-Making and Control Strategy
Enhances the Possibility of Avoidance and
Survival

Meteorological Studies

Sensor Development

Flight Path Optimization

Reactive and Predictive
Feedback Control

FAA Windshear Training Aid

FAA WINDSHEAR TRAINING AID

The FAA Windshear Training Aid was prepared with the support of the Integrated FAA Wind Shear Program. This two-volume manual was written by a team from the airframe industry that interacted with airlines, government, and academia. Principal results are expressed in a variety of ways for executive review, training classes, and public information. One principal goal is to identify the logical connections between pilot observations and pilot actions when wind shear is encountered. The functions that a jet transport aircraft crew should perform are summarized by a flow chart, as shown.

WINDSHEAR SAFETY ADVISOR

The WindShear Safety Advisor (WSA) is a computer program that uses concepts drawn from the world of artificial intelligence (AI) to assess the wind shear threat and to recommend safe piloting action. The current version is an interactive but non-real-time program for studying the input information and logic required to emulate and extend the FAA Windshear Training Aid to on-board computer systems. In particular, the WSA implements the stated rules of the Training Aid, and its development is uncovering the unstated (but critical) implications of the manual. The WSA currently does not address important human factors issues, such as presentation of information to the pilot and requests for pilot input or intervention, which would have little significance in non-real-time simulation. However, our goal is to identify a program structure that is appropriate for real-time use.

ISSUES in MONITORING and RISK ASSESSMENT

Situational Awareness

Reporting of Threat Indicators
Diversity of Information Sources
Relevance to Intended Flight Path
Multiple Reports of Same Phenomenon

Known Limitations to Target Parameter Selection

Runway length, obstacles
Aircraft performance
System malfunctions

Algorithms for Probability of Wind Shear Encounter

LOW plus MEDIUM = HIGH?
Bayesian Logic, Fuzzy Sets?

Admonishment of FAA Pilot Windshear Guide, page 36:

Use of Table 1 (Microburst Winsdshear Probability Guidelines) should not replace sound judgement in making avoidance decisions.

ISSUES in MONITORING and RISK ASSESSMENT

The FAA Windshear Training Aid is a significant achievement in the fight against the hazards of low-altitude wind shear; it identifies the major elements of observational meteorology that can be linked with dangerous wind shears, and it gives jet transport flight crews specific actions to take when wind shear encounter is unavoidable. Nevertheless, it takes a high level of piloting awareness and skill to evaluate the situation and to execute the implied actions correctly and quickly enough to avert catastrophe. To the extent that a computer can be fast and precise, it could assist the flight crew in this dangerous situation.

In seeking to build a computer aid for wind shear avoidance, it is necessary to model the implied logical patterns that the flight crew must use and to quantify subjective rules for computation. Many factors related to situational awareness, limitations to effective action, and efficient decision analysis must be considered, for the computer cannot exert "sound judgment   " without having been programmed to do so.

FAA WINDSHEAR TRAINING AID

One Result of the Integrated FAA Wind Shear Program Plan

Volume 1: Overview, Pilot Guide, and Training Program

Volume 2: Substantiating Data

Model of Flight Crew Actions

```
                    ┌──────────────────────────┐
                    │   Evaluate the Weather    │◄─────────────┐
                    └──────────────────────────┘              │
                                 │                             │
           No          ╱─────────▼──────────╲                 │
     ┌─────────────────  Any Signs of         ╲               │
     │                 ╲  Windshear?          ╱               │
     │                  ╲────────────────────╱                │
     │                     Yes   │                            │
     │                           ▼          ┌──────────────────────────┐
     │                  ╱─────────────────╲  │   Avoid Known Windshear   │
     │                 ╱   Is It Safe       ╲ └──────────────────────────┘
     │                 ╲  To Continue?      ╱         No        ▲
     │                  ╲─────────────────╱───────────────────┘
     │                     Yes   │
     │                  ┌──────────────────────────┐
     │                  │   Consider Precautions    │
     │                  └──────────────────────────┘
     │                           │
     │                  ┌──────────────────────────┐
     └─────────────────►│   Follow Standard         │
                        │   Operating Techniques    │
                        └──────────────────────────┘
                                 │
                   ┌──────────────────────────────────┐
                   │  Windshear Recovery Technique     │
                   └──────────────────────────────────┘
                                 │
                   ┌ ─ ─ ─ ─ ─ ─ ▼ ─ ─ ─ ─ ─ ─ ┐
                     Report the Encounter
                   └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
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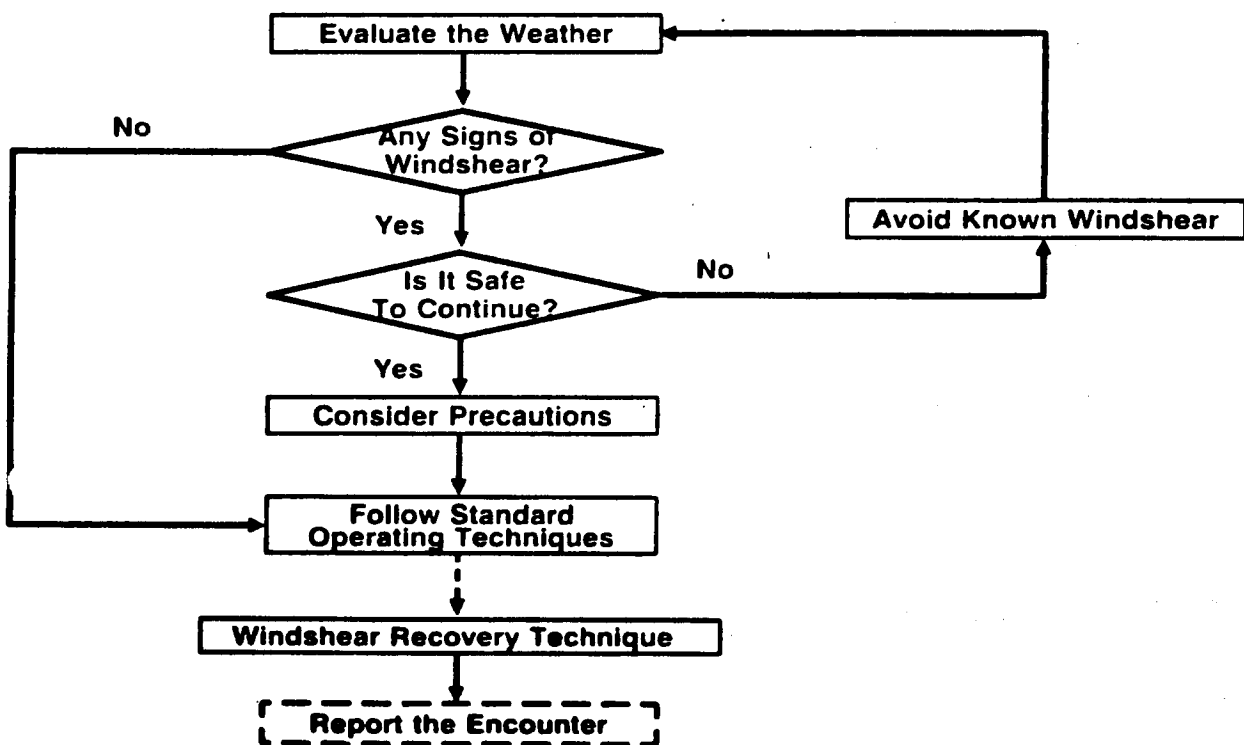
FAA WINDSHEAR TRAINING AID, continued

Flight crews are given information about the likelihood of dangerous wind shear when certain observations are made. If the probability of wind shear is LOW, standard procedures are recommended. If the probability is MEDIUM, the crew is instructed to consider precautions, including delay or alteration of terminal operations. If the probability is HIGH, delay or alteration of terminal operations is recommended, with specifics actions guided by flight phase. If more than observation suggests dangerous wind shear, the subjective probabilities should be added, although the guidelines for the risk assessment and the probability addition are imprecise. For example, two LOWs equal a MEDIUM, and either two MEDIUMs or a LOW and a MEDIUM equal a HIGH. There is no guidance regarding spatial or temporal characteristics of the observations; issues of proximity and degree of intensity are left to the pilot's judgment.

Although the strongest suggestion for piloting strategy is "avoid, avoid, avoid," recommended procedures for recovery or abort following wind shear encounter are given as functions of flight phase. These strategies are sub-optimal, but they materially enhance the probability of survival, in comparison to standard piloting procedures.

FAA WINDSHEAR TRAINING AID,
continued

OBSERVATION	PROBABILITY OF WINDSHEAR
PRESENCE OF CONVECTIVE WEATHER NEAR INTENDED FLIGHT PATH:	
- With localized strong winds (Tower reports or observed blowing dust, rings of dust, tornado-like features, etc.)	HIGH
- With heavy precipitation (Observed or radar indications of contour, red or attenuation shadow)	HIGH
- With rainshower	MEDIUM
- With lightning	MEDIUM
- With virga	MEDIUM
- With moderate or greater turbulence (reported or radar indications)	MEDIUM
- With temperature/dew point spread between 30 and 50 degrees Fahrenheit	MEDIUM
ONBOARD WINDSHEAR DETECTION SYSTEM ALERT (Reported or observed)	HIGH
PIREP OF AIRSPEED LOSS OR GAIN:	
- 15 knots or greater	HIGH
- Less than 15 knots	MEDIUM
LLWAS ALERT/WIND VELOCITY CHANGE	
- 20 knots or greater	HIGH
- Less than 20 knots	MEDIUM
FORECAST OF CONVECTIVE WEATHER	LOW

After Liftoff/On Approach Windshear Recovery Technique

- **THRUST**
  - Apply necessary thrust
- **PITCH**
  - Adjust toward 15°
  - Increase beyond 15° if required to ensure acceptable flight path
  - Always respect stick shaker
- **CONFIGURATION**
  - Maintain existing configuration

WINDSHEAR SAFETY ADVISOR

FAA Windshear Training Aid

Expansion to Include Implications
and Data Input/Output

Cockpit Simulation

On-Board Data

Inertial Sensors
Air Data Sensors
Weather Radar

Visual Observations
Look-Ahead Sensors

**WindShear
Safety
Advisor**

External Data

Weather Reports
Tower Reports
LLWAS
PIREPs
SIGMETs

NEXRAD
TDWR

Flight
Crew
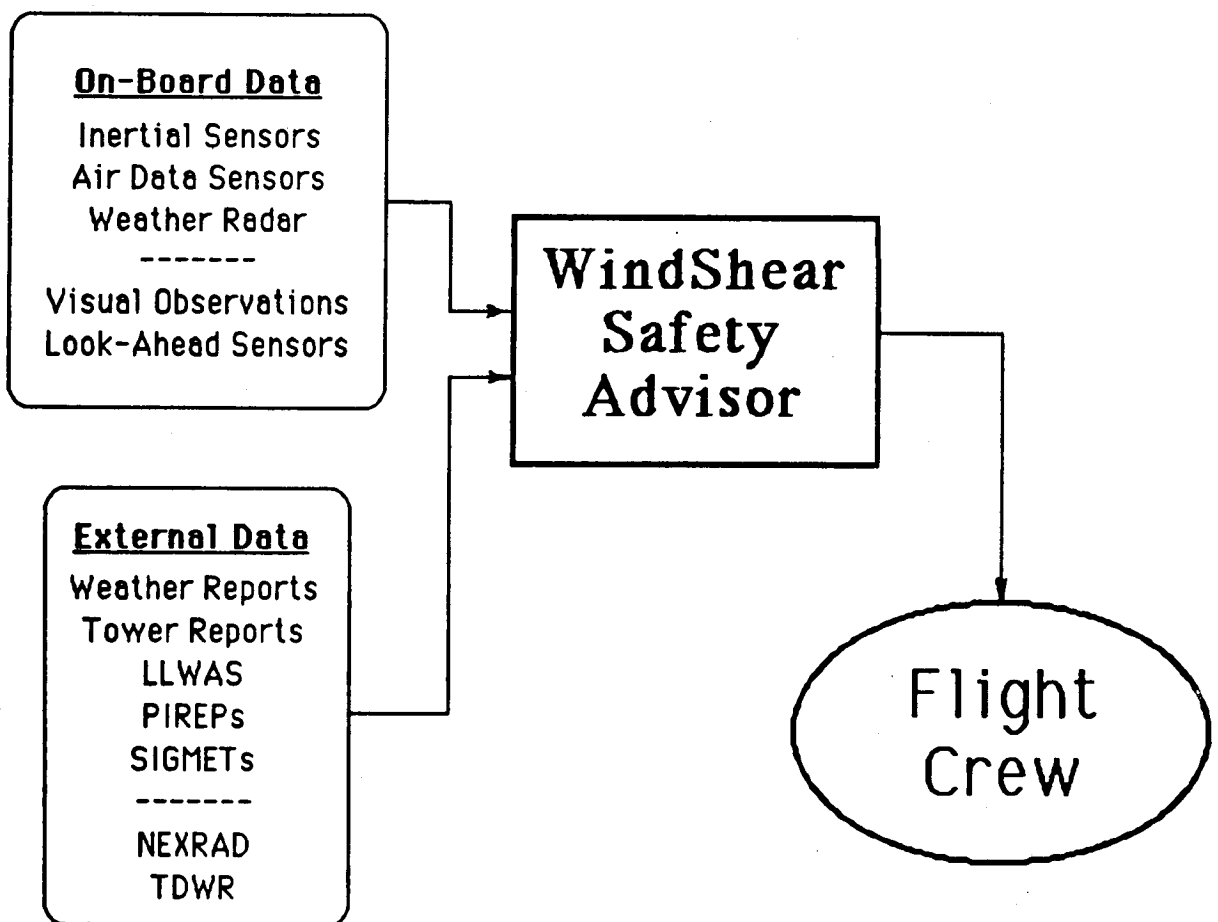
RULE-BASED SYSTEM for CONTROL

An on-board implementation of the WSA would be a Rule-Based Control (RBC) system having attributes of both expert systems and conventional controllers. In the parlance of AI, the Inference Engine executes the intelligence of the system, drawing on the Data Base for information (in the form of parameter values and properties) and on the Rule Base for logical relationships (in the form of IF...THEN or PREMISE...ACTION statements). In "firing" the rules, the Inference Engine may require that certain side tasks be accomplished, such as taking measurements, making estimates, computing control settings, and transferring commands to control effecters. Continuing the AI jargon, this procedural, quantitative computation is done in a Side Effects Engine that calls on both the Data Base and an Algorithm Base for its knowledge. (Measurement and control are considered side effects of the request for information and the decision-making process.)

Decision and control functions are readily separated in an RBC system, the former calling for symbolic computation, the latter for numeric computation. (In either case, the digital computer simply moves bits around; however, interpretations of the logical operations are different.) Not surprisingly, some computer programming languages are better than others at performing the two types of tasks, so it is most efficient to use different languages for decision and control during the development phase. For example, LISP is a good language for developing logical relationships among strings of symbolic data, while Pascal or FORTRAN is a good language for numerical computation. Consequently, LISP is the language of choice for current WSA development.

Once decision and control functions have been defined, they must be merged (in some sense) in the RBC system. It would be rare indeed for a given application to need all the subtle features of either development language; thus a single language can be used at the final step. Development of a real-time version of an RBC system is thus aided by one or more language translators that efficiently transform subsets of the development languages into the final code. Experience with current compilers and computers indicates that procedural languages like Pascal, FORTRAN, and C produce fast, concise target code for both decision and control.

RULE-BASED SYSTEM for CONTROL
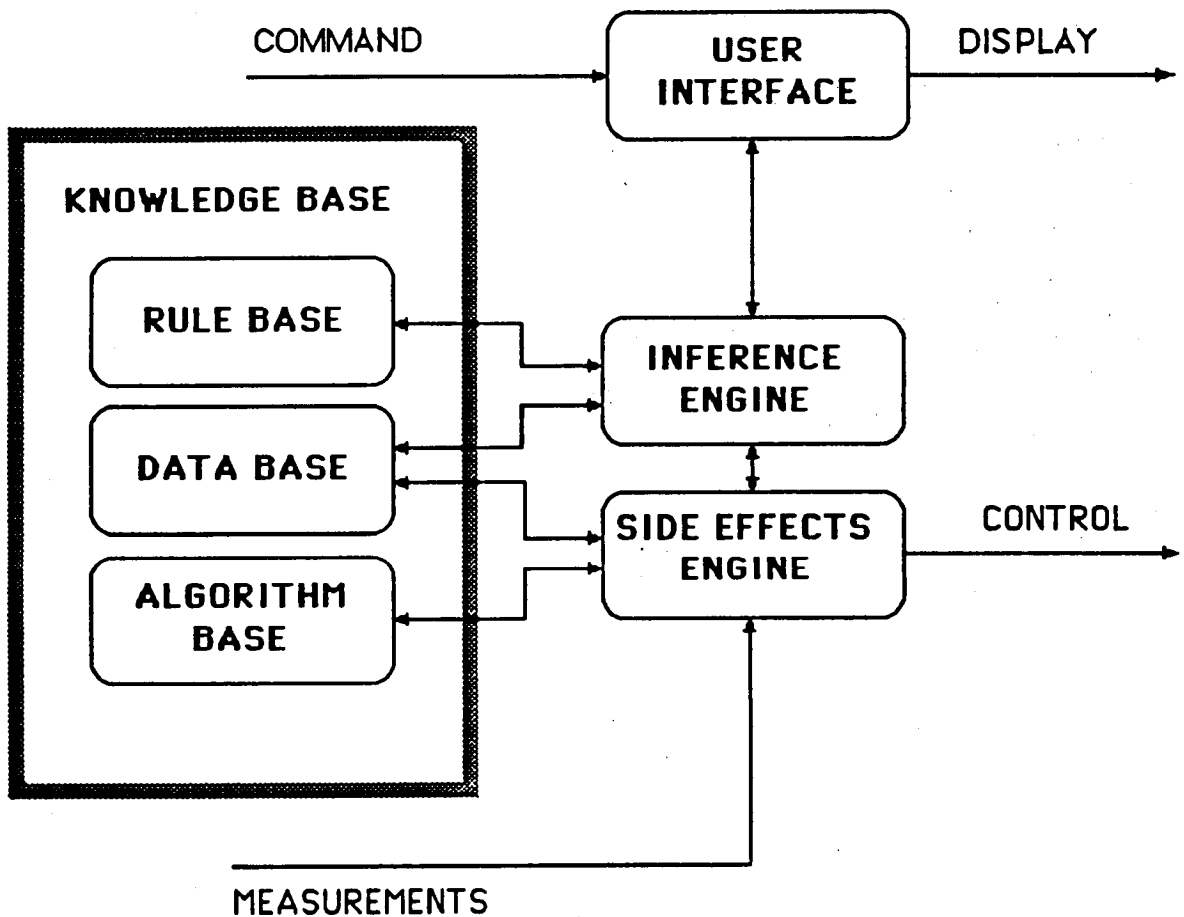
Partitioning for Decision and Control Functions

Integration of Symbolic and Numeric Computation

GRAPHICAL REPRESENTATION of KNOWLEDGE

The elements of decision making needed for the WSA are illustrated by this simple example. A *parameter* is a quantity that can have several values as well as an array of complicated properties (not shown). A *rule* accepts one or more parameters as its *premise* and performs the *action* of setting another parameter if the values of its input parameters make the rule true. For the premise to be true, it may be necessary that *all* multiple parameters take certain values (represented by the arc between connecting lines), or it may be sufficient for *any* parameter to take a certain value (represented by no arc between channels into the rule).

The example shown illustrates such a rule: Rule 1 says that IF the flight phase is approach AND the aircraft is below a critical altitude AND a stable glideslope has not been established, THEN the pilot should perform a go-around. Rule 2 is the logical exclusion of Rule 1 and need not be implemented; it is here just for demonstration. Note that the go-around decision proceeds from the rule; in an array containing a number of such rules, setting parameters by moving from the bottom up is called *forward chaining*. Sometimes a result is known and it is necessary to determine what combination of parameters might have caused the result. Answering this question requires *backward chaining*, that is, moving through the rules from the top down. The WSA requires that both types of chaining be used at different times.

GRAPHICAL REPRESENTATION
of KNOWLEDGE

PARAMETER

VALUE 1	VALUE 2	VALUE 3	PARAMETER NAME

RULE

RULE NAME

ACTION Sets Values of Parameters

PREMISE Tests Values of Parameters

AND OR

EXAMPLE

TRUE	FALSE	GO AROUND

RULE 1

RULE 2

Forward Chaining

Backward Chaining

TRUE	FALSE	APPROACH

TRUE	FALSE	BELOW CRITICAL ALTITUDE
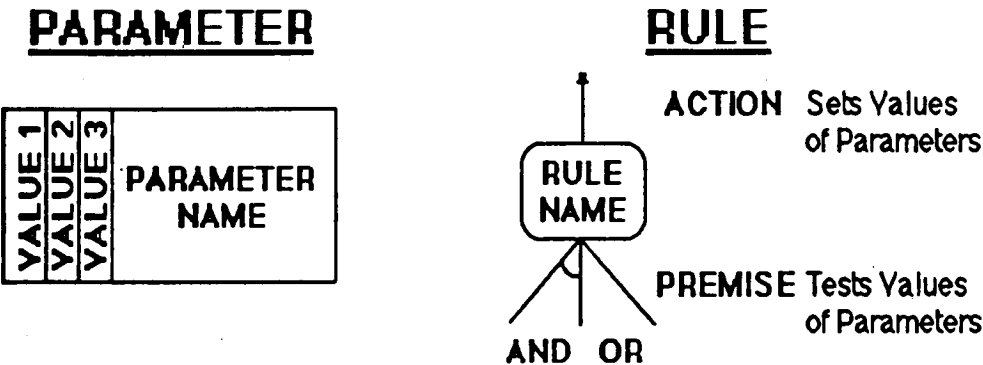
TRUE	FALSE	GLIDESLOPE NOT STABLE
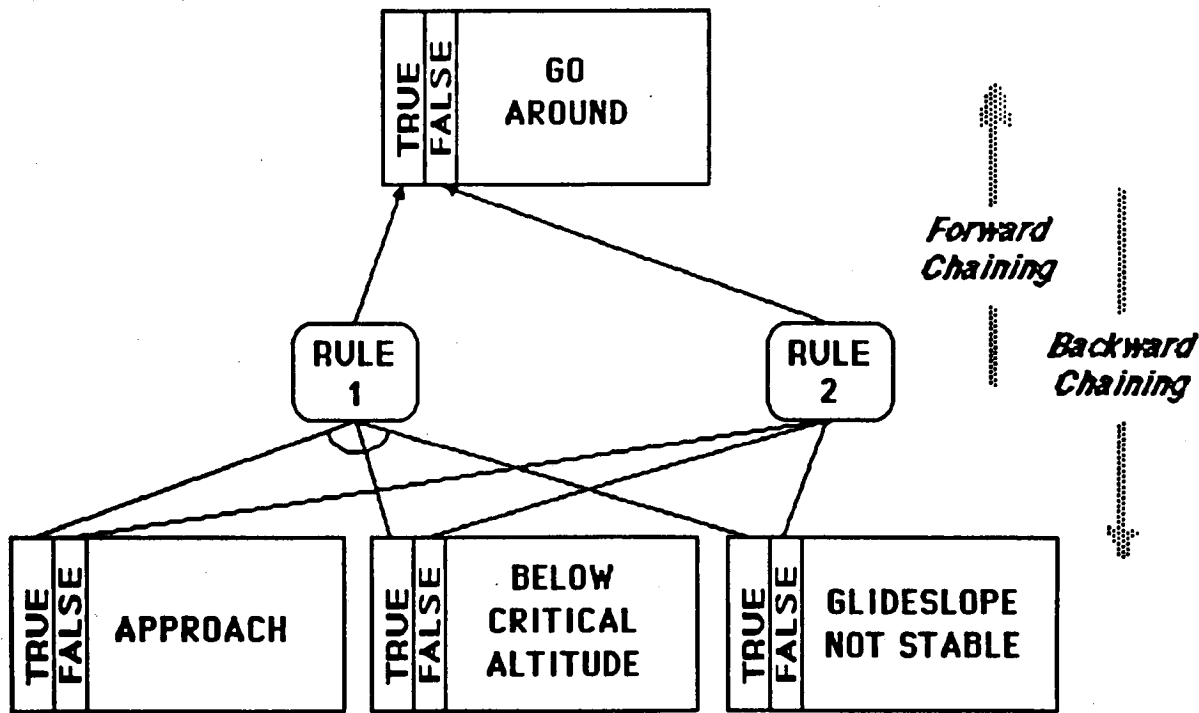
STRUCTURE of a RULE

The current version of WSA defines each rule as a *list* in the computer language called Common LISP. Thus, each rule is expressed as follows:

(name, premise, action, par-act, par-pre, translate)

The meaning of each list element is defined on the chart. The Inference Engine effectively takes this list apart to find the needed inputs and outputs, performing an IF...THEN operation on the appropriate parts.

STRUCTURE of a RULE

NAME   Name of the Rule

PREMISE   Logical Relation of Parameters to
                   be tested by the Rule

ACTION   Logical Result of Rule being TRUE

PAR-ACT   Parameters set by Action

PAR-PRE   Parameters tested in Premise

TRANSLATE   Documentation String for
                   Optional Display

[Implemented as a Common LISP *LIST*]

RULE BASES of the WINDSHEAR SAFETY ADVISOR

The current WSA version contains over 140 rules that set over 80 parameters. They are organized in the left-to-right hierarchy shown, addressing the functions defined by the FAA Windshear Training Aid.

RULE BASES of the
WINDSHEAR SAFETY ADVISOR

Executive

        Mission Phase
        Communication

Wind Shear Alert

        Wind Shear Detection
        Flight Path Deviation

Risk Assessment

        PIREP-LLWAS
        ATIS-SIGMET
        Generic Weather Risk
        Heavy Precipitation
        Rainshower
        Lightning
        Virga
        Turbulence

Action

        Standard Procedures
        Recovery Procedures
        Go-Around Procedures
        Delay Procedures

Planning

        Runway
        Airspeed
        Flaps

STRUCTURE of a PARAMETER

The parameters of the WSA currently are defined as Common LISP *variables*. There are different classes of parameters, defined by how and when their values are determined. A variable has the value *current*, to which is appended a *property list* containing (*use, update, expect, translate*), defined in the chart.

STRUCTURE of a PARAMETER

Parameter Classifications

INTERNAL   Parameter is internal to the Expert System; Value defined by a Goal-Directed Search

PRESET   Parameter is set by Initialization

STATE   Parameter is set by an Estimator

OUTSIDE   Parameter is set outside the Expert System

Parameter Properties

CURRENT   Current Value of the Parameter

USE   Rules that Use the Parameter

UPDATE   Rules that Set the Parameter

EXPECT   Allowable Values of the Parameter

TRANSLATE   Description of the Parameter for Optional Display

[Implemented as a Common LISP *VARIABLE*]

EXAMPLE PARAMETERS of the WINDSHEAR SAFETY ADVISOR

Names of some of the WSA parameters are shown and are, for the most part, self-explanatory. Each parameter may represent not only a symbolic or numerical value but a list that further defines its properties. Therefore, the Inference Engine can readily identify parameters that have certain attributes, in turn, aiding the searches associated with monitoring, assessment, planning, and action.

EXAMPLE PARAMETERS of the
WINDSHEAR SAFETY ADVISOR

Communication Rule Base

New-information-received
Incident-reported
Tower-informed-goa
Tower-informed-delay
Precautions-taken

Flight Path Deviation Rule Base

Target-airspeed
Airspeed-deviation
Max-airspeed-deviation
Agl-at-max-speed-deviation
Target-vertical-speed
Vertical-speed-deviation

Outside Parameters

PIREP
LLWAS
Dispatch-office
ATIS
ASWW
SIGMET
Onboard-radar
Tower-report
TDWR
Wind-profiler

LABORATORY for CONTROL and AUTOMATION

Development of the WindShear Safety Advisor is being conducted within the Princeton University Department of Mechanical and Aerospace Engineering's Laboratory for Control and Automation. The laboratory has a broad variety of computational tools that are appropriate to research in artificial intelligence, computer-aided design, flight dynamics, and digital control. A real-time expert system for fault-tolerant control of a tandem-rotor helicopter has been implemented in the laboratory using three 80286 MULTIBUS computer boards for execution. Current WSA development makes use of the LISP Machine, which employs Common LISP for the expert system and FORTRAN for flight simulation.

LABORATORY for
CONTROL and AUTOMATION

Symbolics 3670 LISP Machine

Silicon Graphics IRIS 3020 Workstation

Macintosh II

IBM PS-2/80

IBM PC-AT (2)

IBM PC/XT (2)

Lab-wide Ethernet Connection (TCP/IP)

Broadband Connection to IBM 3081s
and ETA^{10}s

Portable and Fixed MULTIBUS
Computers (5)

Fixed-Base Cockpit Simulator

DEVELOPMENT SCREEN for WINDSHEAR SAFETY ADVISOR

A typical LISP Machine display for WSA development is shown. The program developer uses a mouse to invoke features listed on the menu line and types information into the User Interaction Pane (or window). Parameters that change as a result of WSA activity are highlighted in the Parameter Information Pane, while the overall behavior of the expert system can be followed in the Result Monitoring Pane. This display is not intended as a prototype cockpit display but as an engineering tool for concept and program development.

DEVELOPMENT SCREEN
for
WINDSHEAR SAFETY ADVISOR

Princeton WindShear Safety Advisor Interface	
Flight Plan Get Value Of Make Message Presets .... *(Menu Line)*	
User Interaction Pane	**Parameter Information Pane**
• *Messages to program developer* • *Messages to crew, tower, etc.* • *Data and commands from program developer*	• *Parameters that have changed values* • *Other parameters of interest*
Result Monitoring Pane	
• *Executive observations* • *Monitored information* • *Status assessment*	• *Planning activity* • *Recommended action* • *Current airport weather*

LISP Machine Implementation
for Concept/Program Development

Interface to FORTRAN
Flight Simulation

CONCLUSION

The WindShear Safety Advisor program implements the stated decision-making logic of the FAA Windshear Training Aid, as well as a set of unstated implications that are necessary for practical application. The WSA expert system contains over 140 rules that set over 80 parameters for terminal operations of jet transport aircraft. Future modifications will account for spatial and temporal variations of the aircraft and its meteorological environment, as well as for interfaces with the air traffic control system. The WindShear Safety Advisor sets the stage for cockpit simulation of logic for wind shear avoidance, which, in turn, will lead to practical systems for operational aircraft.

CONCLUSION

Logic of Wind Shear Avoidance

Computer Aiding for Crew Decisions

Spatial and Temporal Factors

Off-Line and On-Line Simulation

Interfaces with Sensors, Aircraft,
and Crew

Session II. Airborne–Flight Management

The Effect of Wind Shear During Takeoff Roll on Aircraft Stopping Distance
Terry Zweifel, Honeywell/Sperry

NASA

SECOND COMBINED MANUFACTURERS' AND TECHNOLOGY AIRBORNE WINDSHEAR REVIEW MEETING

OCTOBER 18 - 20, 1988
WILLIAMSBURG, VIRGINIA

THE EFFECT OF WINDSHEAR DURING TAKEOFF ROLL ON AIRCRAFT STOPPING DISTANCE

PRESENTED BY:

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THE EFFECT OF WINDSHEAR DURING TAKEOFF ROLL ON AIRCRAFT STOPPING DISTANCE

527368

Terry Zweifel
Sperry Commerical Flight Systems Group
Honeywell, Inc., Phoenix, Arizona
3 February 1988

ABSTRACT

A simulation of a Boeing 727 aircraft during acceleration on the runway is used to determine the effect of windshear on stopping distance. Windshears of various magnitudes, durations, and onset times are simulated to assess the aircraft performance during an aborted takeoff on five different runway surfaces. A windshear detection system, active during the takeoff roll and similar to the Honeywell Windshear Detection System is simulated to provide a discrete to activate aircraft braking upon shear detection.

The results of the simulation indicate that several factors affect the distance required to stop the aircraft. Notable among these are gross weight, takeoff flap position, runway characteristics, and pilot reaction time. Of the windshear parameters of duration, onset and magnitude, magnitude appears to have the most significant effect.

INTRODUCTION

Low-level windshears have proven to be one of the most significant threats to aircraft safety. Several aircraft accidents have been directly attributed to the phenomenon, and, as a result, considerable progress has been made in the understanding of the atmospheric mechanisms, methodology of detection, and the control of the aircraft's flight path during a shear encounter.

The research has also resulted in the development of several on-board systems which have been certified by the FAA and are currently in use. These systems have proven effective in detecting the presence of a windshear and, in at least two cases, have been instrumental in the successful escape from an encountered windshear.

One aspect of the windshear problem which has not been adequately addressed, however, is the effect of windshear on the aircraft during takeoff roll: the time between the initial acceleration of the aircraft on the runway and lift off. Several cases of windshear encounters during the takeoff roll are known, the most notable being the incident of United Airlines Flight 663 at Stapleton International Airport on May 31, 1984. In this instance the aircraft, a Boeing 727, encountered the

localizer antenna located 1074 feet (327 m) beyond the departure end of the runway. Fortunately, no injuries occurred, but substantial damage was done to the aircraft.

If a flight crew is aware of a windshear condition prior to obtaining the critical engine failure speed, V_1, they may elect to either abort the takeoff or to continue on through rotation and lift off. V_1 is thus a "go, no-go" speed which is generally determined by the aircraft's ability to stop within the remaining runway distance. V_1 is defined as a calibrated airspeed and thus differs from the actual ground speed of the aircraft by the magnitude of the wind. Consequently, the attainment of V_1 in a windshear condition does not necessarily assure that the aircraft can be safely stopped on the runway since the ground speed, and hence the kinetic energy of the aircraft, can be significantly higher than normal. The additional kinetic energy of the aircraft may result in a substantial increase in the required runway to safely stop the aircraft should the flight crew elect to abort the takeoff.

If the windshear is detected after obtaining V_1, the takeoff must be continued in most cases as the available runway to stop the aircraft is usually insufficient.

This paper addresses the problem of windshear occurring during takeoff roll by simulating an aircraft in various magnitudes, durations, and onset times of windshears, at different aircraft weights, and on different runway surfaces.

SIMULATION CONFIGURATION

A Boeing 727 aircraft was simulated on an Epson Equity III+ computer as a three degree of freedom model with an effective one-quarter second computational rate. Lift and drag were computed from curve fits of actual aircraft data with the assumption made that angle of attack, alpha, is constant during the ground roll. Ground effect on lift and drag were included in the simulation.

Thrust was computed from curve fits of Thrust/Delta versus Mach number for a fixed takeoff engine pressure ratio (EPR). The engines simulated were Pratt and Whitney JT8D-15 engines. To simulate engine spool down, a simple lag filter was utilized. Engine thrust reversers were not simulated.

The lift and drag effect of ground speedbrakes was simulated with the assumption that the ground speedbrakes achieve maximum deployment within 1 second.

The aircraft's antiskid system was simulated by assuming 60% efficiency in achieving the maximum coefficient of friction available for the runway surface.

Five runway surfaces were simulated: (a) dry surface; (b) wet, grooved asphalt; (c) wet, grooved concrete; (d) wet, textured asphalt; and (e) wet, textured concrete. The dry surface coefficient of friction was applicable to either asphalt

or concrete. Coefficients of friction were derived from curve fits of available data and are shown on Figure 7.

Windshear models available were a linear horizontal shear and a vortex microburst model. The former was used for the simulation runs since it allowed more precise control of shear onset, magnitude, and duration.

The runway altitude was sea level for all cases and the ambient temperature assumed to be standard day, 59 degrees F (15 degrees C). The runway was assumed to have zero slope.

No explicit pilot model was necessary as braking is done by the antiskid system; however, recognition delays were incorporated to approximate pilot response. For all runs except those directed at pilot recognition time, the delay used was 1 second.

AIRCRAFT CONFIGURATION

The simulated flap setting for most takeoffs was 15 degrees, the most common setting for this aircraft. Aircraft weight could be varied, but, as might be expected, the heavy weight aircraft was most severely affected by the shears. To achieve worst case conditions, the aircraft weight was set at 210,000 pounds (95254 Kg). Other runs, not included in this paper, were conducted at 140,000 pounds (63503 Kg) and 175,000 pounds (79378 Kg).

SIMULATION RUNS

The aircraft was initialized at the end of the runway with full takeoff power set and brakes applied. At the start of the run, the brakes were released and the aircraft allowed to accelerate.

The simulated runway was infinitely long to preclude the complexity of altering aircraft weight and flap setting to produce a balanced field length. In this way, the worst case aircraft weight could be used throughout the runs.

To provide baseline data in no shear conditions, an aborted takeoff was performed when the aircraft achieved V_1. Following the recognition delay, the thrust was reduced to idle, the ground speed brakes deployed, and the antiskid system activated to provide braking. The total runway used thus provided a baseline value for comparing the effect of a windshear.

RUNWAY SURFACE TYPES

As windshears may or may not be accompanied by rain, it is important to assess the aircraft's performance on both dry and wet runways. A wet runway is assumed to have from 0 to .5 inch (1.27 cm) of standing water. The type of runway surface

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can also have significant effects on braking performance. Consequently, the studies used grooved and textured asphalt and concrete runways. For convenience, mnemonics were used for the runway types according to Table 1:

Table 1

Mnemonic	Runway Surface
DRY	Dry Asphalt or Concrete
GVD ASPH	Wet, Grooved Asphalt
GVD CONC	Wet, Grooved Concrete
TEX ASPH	Wet, Textured Asphalt
TEX CONC	Wet, Textured Concrete

EFFECT OF FLAPS ON STOPPING DISTANCE

The flight crew's selection of takeoff flaps significantly alters the amount of runway required to stop the aircraft. The total runway required to accelerate the aircraft to V_1 and then come to a complete stop using the available takeoff flap settings for the Boeing 727 is shown on Figure 1. Clearly, the flap setting of 25 degrees provides the minimum runway usage. This is primarily because V_1 for 25 degrees of flaps is significantly lower than the others. Consequently, the aircraft achieves V_1 with lower runway usage and also has a lower kinetic energy.
However, consideration must be given to aircraft performance once airborne in the event the flight crew elects to continue the takeoff. For the Boeing 727, for example, a flap setting of 15 degrees is preferred for airborne performance and consequently, 15 degrees should be used as a compromise between stopping distance and airborne performance.
As the incremental runway distance between a flap setting of 5 degrees and 15 degrees is significantly more than that between flap settings of 15 and 25 degrees, one must conclude that a flap setting of 5 degrees for takeoff should not be used if windshear is suspected.

EFFECT OF WINDSHEAR ONSET

To assess the effect of shear onset time on stopping distance, a constant shear of 5 knots per second (2.57 m/sec/sec) was introduced at specified points as the aircraft accelerated. The shear, once started, was of infinite duration. Upon detection and recognition of the shear, the takeoff was

aborted. As can be seen in Figure 2, the total runway used in most cases was less than or equal to the distance for the no shear case. The times on the Figure indicate the time of shear onset as measured from initial brake release.

In the cases where shear onset occurred slightly before obtaining V_1 speed, the total runway usage was increased, but not dramatically so.

EFFECT OF WINDSHEAR DURATION

The effect of the duration of several shears of different magnitudes was investigated to determine the increase in total runway used in coming to a complete stop. In each case, the onset of the shear was at approximately 10 knots before V_1 speed. Figure 3 illustrates the results. The ordinate axis yields the total runway used in thousands of feet. The magnitude of the shear used was 5 knots per second. For the dry runway or wet, grooved runways the additional runway used is virtually independent of shear duration.

For the wet, textured asphalt or concrete runway, noticeable increases in runway used are evident. However, once the duration of the shear exceeds 15 seconds, the total runway used is approximately constant, leading one to conclude that shear duration is not a prime consideration except on textured surfaces.

EFFECT OF WINDSHEAR MAGNITUDE

A series of runs was conducted in which the shear onset, detection, and reaction coincided with attaining V_1. After onset, the shear was sustained indefinitely. Figure 4 illustrates the results of the simulation runs. The ordinate axis gives runway distance in thousands of feet.

The data indicate that shear magnitude is not of prime concern for the dry or wet, grooved surfaces. Significant increases in total distance used are evident in the wet, textured surfaces, however.

EFFECT OF UNDETECTED WINDSHEARS

As of the time of this writing, no on-board system is available that will detect a shear during takeoff roll, although one such system is now in the certification process. Consequently, it is left to the flight crew to determine whether or not a windshear is present during takeoff roll. The detection of such shears can be difficult since the aircraft is accelerating and the shear may be accompanied by turbulence. In the simulation runs, the magnitudes of the shears were intentionally made small to simulate shears that might go unnoticed by the flight crew. The onset of the shears occurred approximately 10 knots before V_1 speed and the shear was then

maintained indefinitely. When the aircraft achieved V_1 speed, it was braked to a full stop and the total runway used noted. A graph of total runway used versus shear magnitude is shown on Figure 5. Undetected shear magnitudes of 2 knots per second or less have profound effects on the total runway used, particularly for the heavy weight aircraft. This is a consequence of shear causing a low air mass acceleration which, in turn, causes V_1 speed to be achieved much further down the runway than normally.

EFFECT OF PILOT RECOGNITION

To assess the effect of a recognition delay in reacting to a detected shear condition, simulation runs were made with reaction delays of 0, 1, 2, 3, 4, and 5 seconds. The results of the runs are shown on Figure 6. In these cases, a 5 knot per second infinite shear began at V_1. The reaction time represents the number of seconds between detection of the shear and the pilot reaction of reducing thrust, braking, and deploying the ground speed brakes. As can be seen, the effects are dramatic, particularly for the longer delay times. On the average, about 4% more runway is used for each additional second of delay, regardless of the surface type.

CONCLUSIONS

The data indicate that flap setting, runway surface type, and pilot recognition time are all prime factors in determining total runway used. A worst case scenario for this aircraft would be heavy gross weight with 5 degree takeoff flaps on a wet, textured concrete runway. A long recognition time further aggravates the situation.

Consequently, one may conclude that the largest possible takeoff flap setting consistent with good airborne performance should be used. For the 727 aircraft, this is a flap setting of 15 degrees.

Timely pilot recognition and reaction to a windshear condition on takeoff should and can be reenforced by simulator training. As mentioned above, approximately 4% more runway is used for each second of pilot reaction time. It is difficult to overemphasize the necessity for rapid response to a windshear condition, particularly if the takeoff is to be aborted.

It is interesting that windshears occurring on dry; wet, grooved asphalt; and wet, grooved concrete runways have such a small effect on braking performance. With a shear magnitude of 5 kt/sec occurring at V_1, typical increases in required distance were of the order of 1%.

The effect of ungrooved runway surfaces, however, is significant. A 5 kt/sec shear encountered at V_1 increases the total runway usage by almost 12% for a wet, textured concrete surface. The corresponding number for the asphalt runway is 5.4%. It should be noted also, however, that an aircraft on a

wet, textured concrete runway requires about 46% more distance to stop even without a windshear than would be needed if the runway surface were dry.

The effect of shear onset and shear duration did not appear to seriously affect the aircraft's braking performance. Of the detected shears, shear magnitude seemed most significant in terms of braking distance.

Undetected shears resulted in large increases in runway required - up to 56%. However, it is unlikely that the pilot would elect to abort in these cases. It is also unlikely that a low level shear would be sustained for long periods of time. The simulations did provide an indication of the importance of shear detection on the runway, however.

It is important to note that the effect of Windshear Detection System delays were not included in the analysis. Detection delays due to computation and filtering can add appreciably to the total runway used in a windshear condition. The effect of the delays is comparable to the pilot reaction delays discussed in the paper: for each second of delay time, up to 4% more runway may be required to stop the aircraft.

RUNWAY USED IN BRAKING FROM V1

210 K LB 727, -15 ENGINES, NO SHEAR

FLAPS = 5

RUNWAY SURFACE

15

25

TOTAL RUNWAY USED IN FEET
(Thousands)
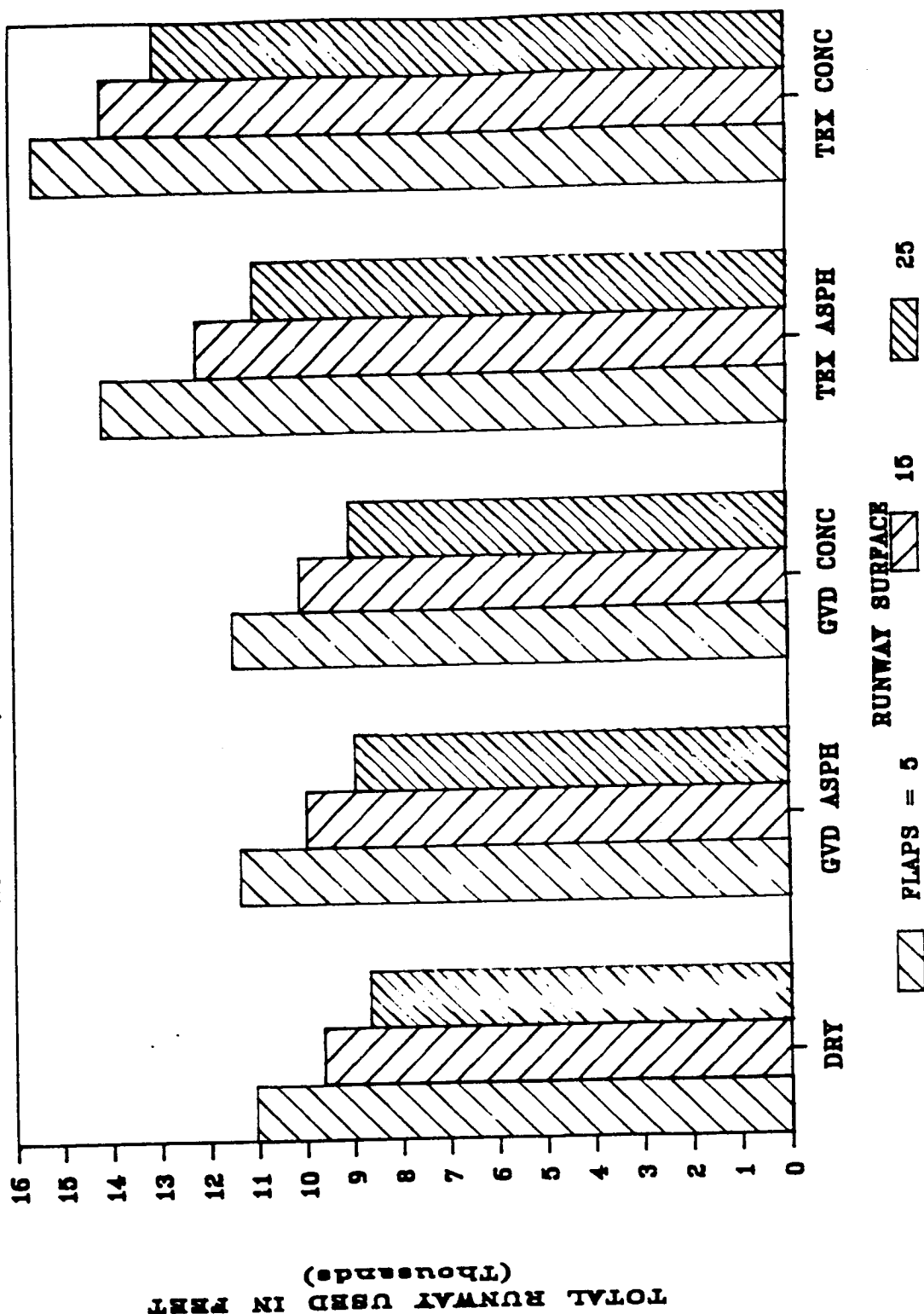
DISTANCE AS A FUNCTION OF SHEAR ONSET

TOTAL RUNWAY USED IN FEET
(Thousands)

18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

DRY   GVD ASPH   GVD CONC   TEX ASPH   TEX CONC

RUNWAY SURFACE TYPE

10 SEC   20 SEC   30 SEC   40 SEC   V1
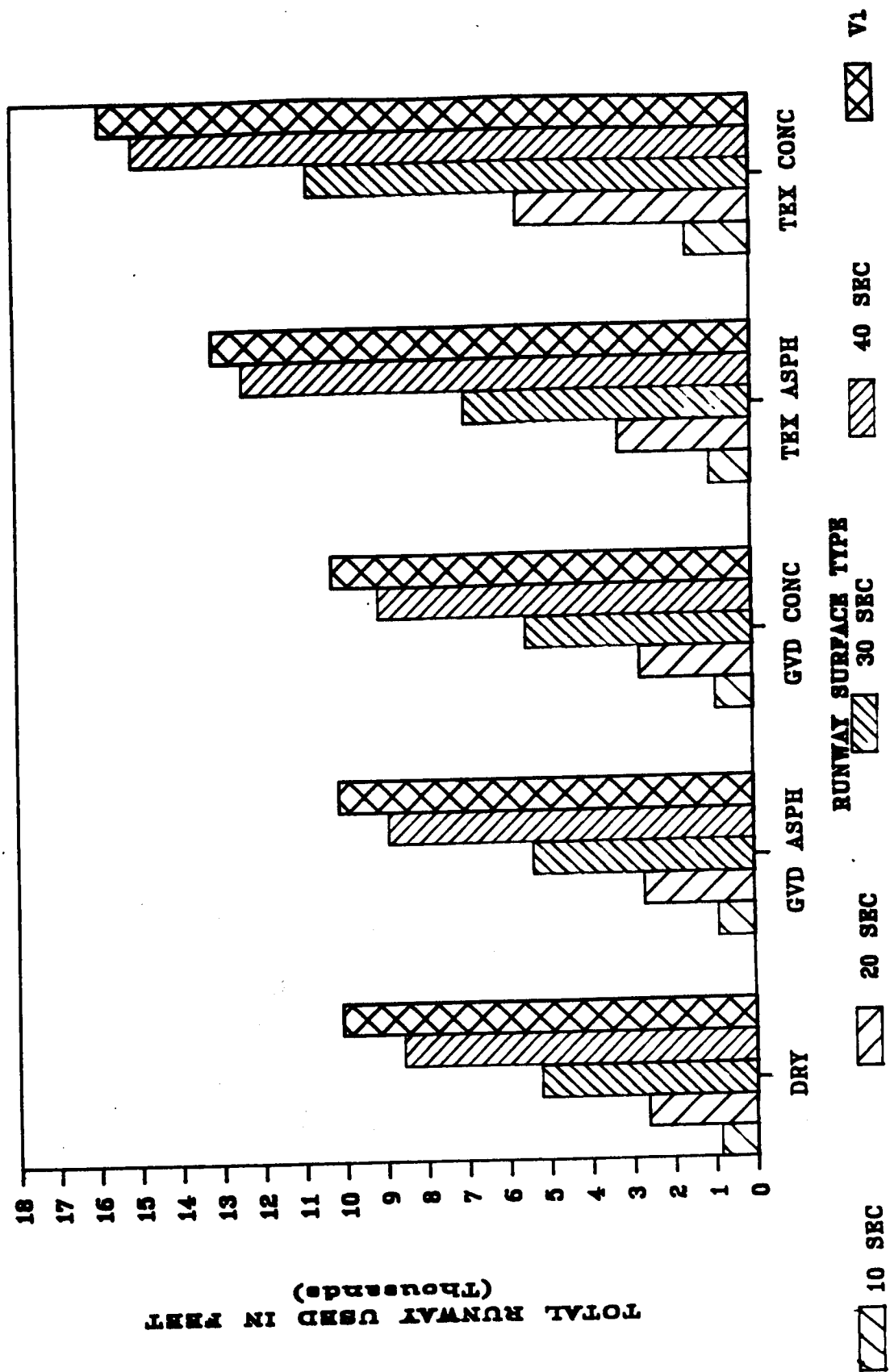
FIGURE 3

EFFECT OF SHEAR DURATION

210 K LB 727, FLAPS 15, 5 KT/S SHEAR

FIGURE 3

558
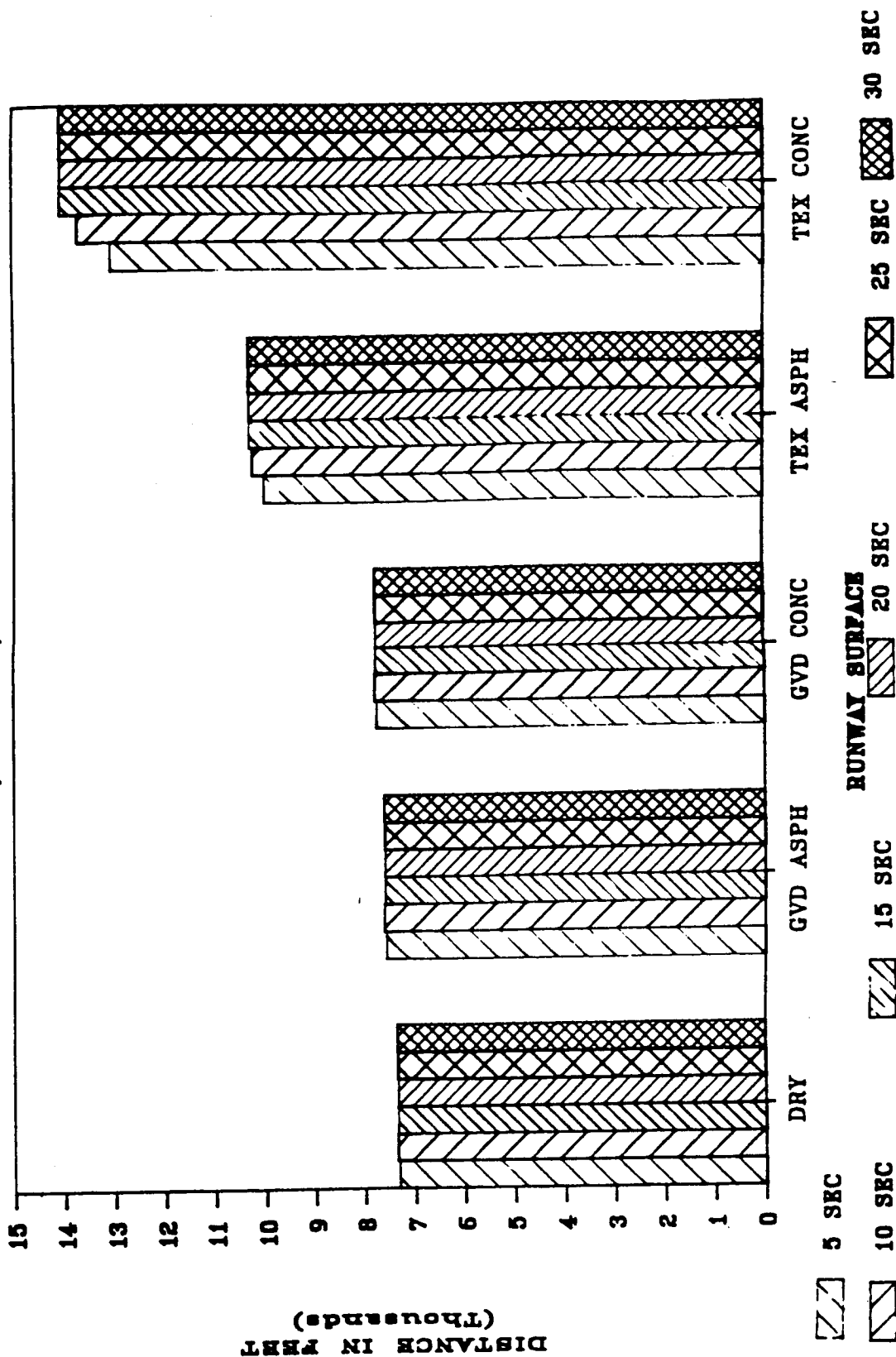
EFFECT OF SHEAR MAGNITUDE

210 K LB 727, FLAPS 15, INFINITE DUR.
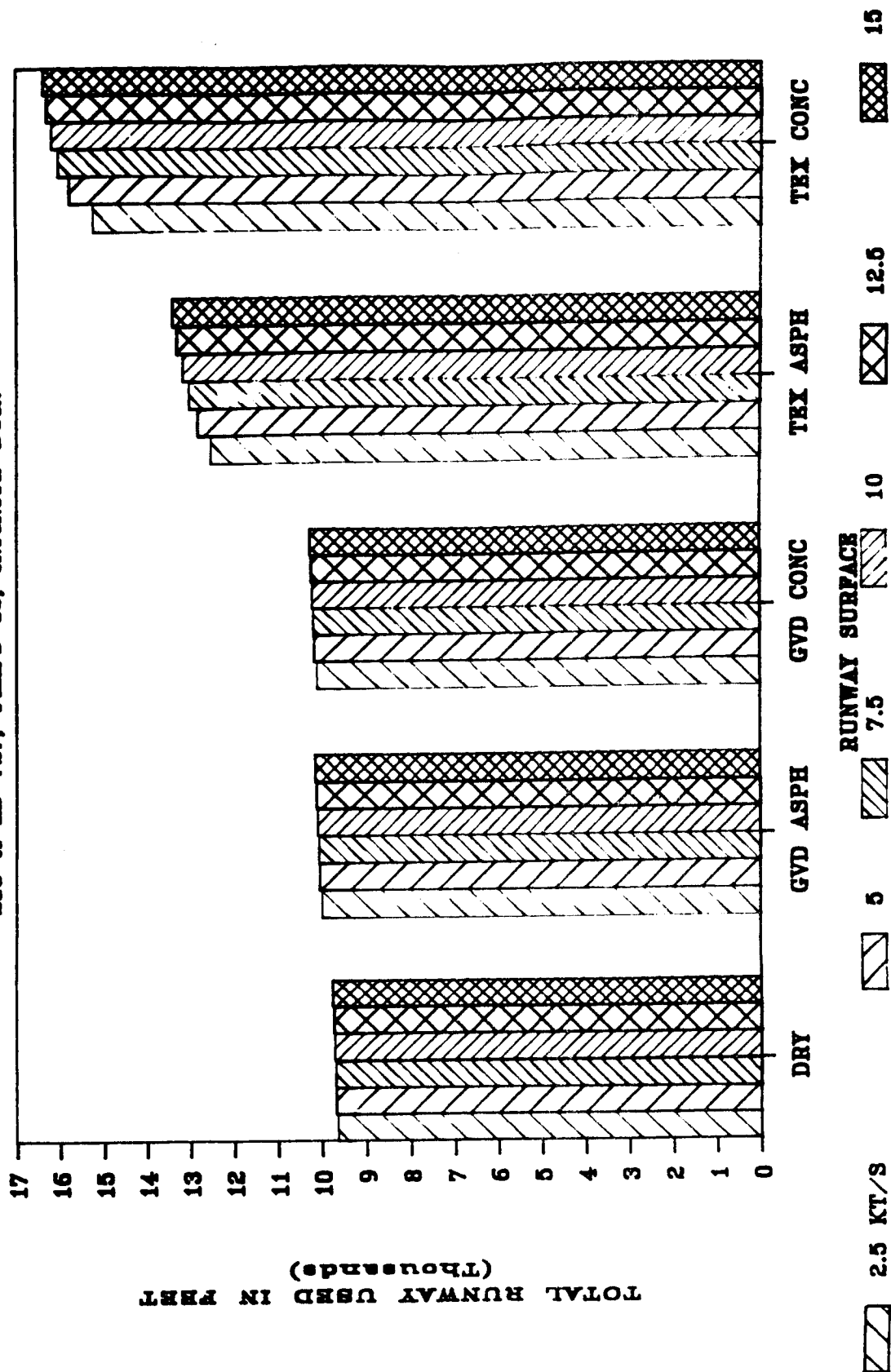
FIGURE 4

UNDETECTED SHEARS

210 K LB 727, FLAPS 15, 30 SEC DURATION

DRY W.G. ASPH W.G. CONC W.T. ASPH W.T. CONC

RUNWAY SURFACE

TOTAL RUNWAY USED IN FEET
(Thousands)

NO SHEAR   .5 KT/S   1 KT/S   1.5 KT/S   2

FIGURE 8

560
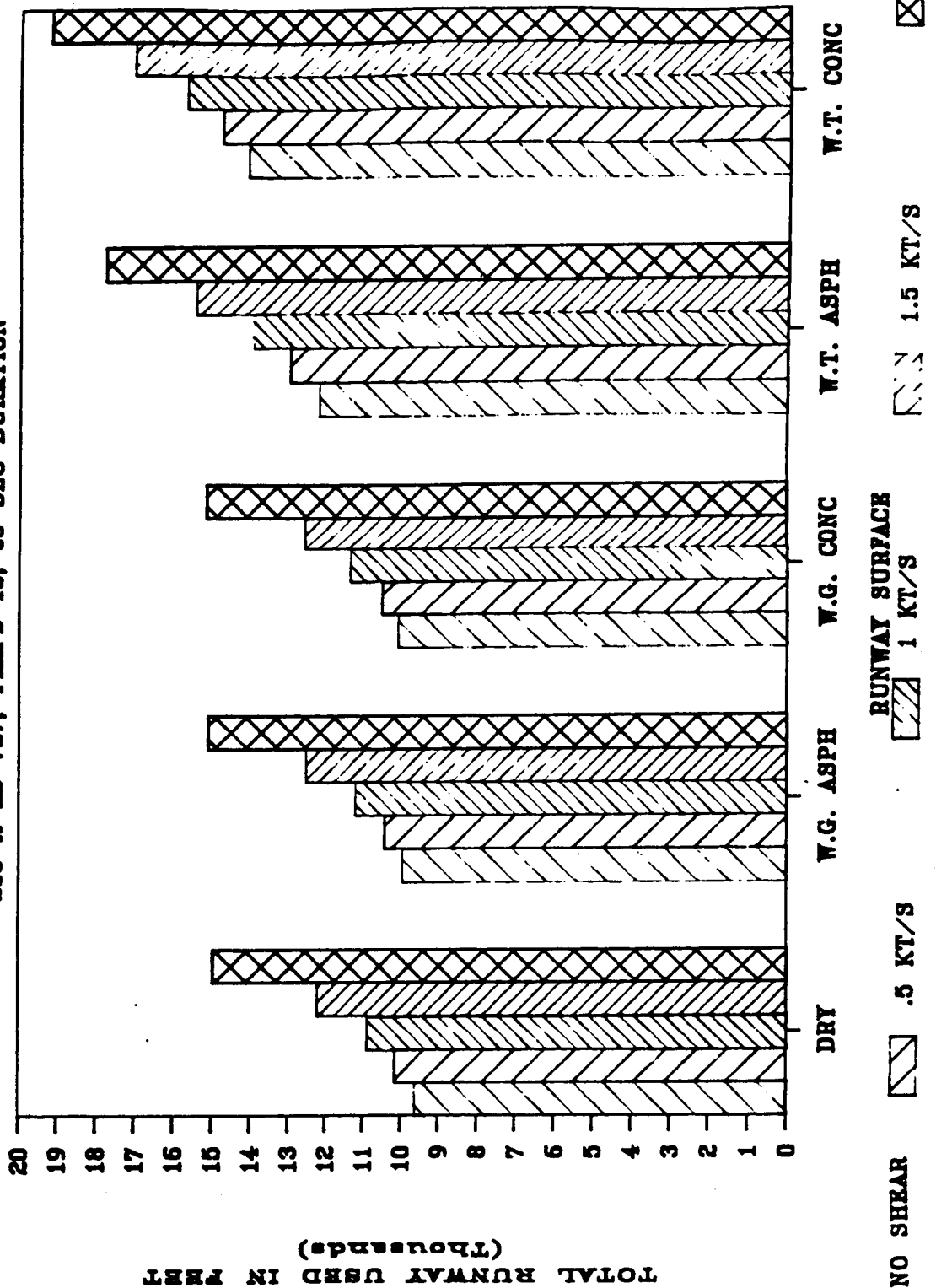
EFFECT OF PILOT REACTION TIME

210 K LB 727, FLAPS 15, 5 KT/SEC INP.

FIGURE 6

561
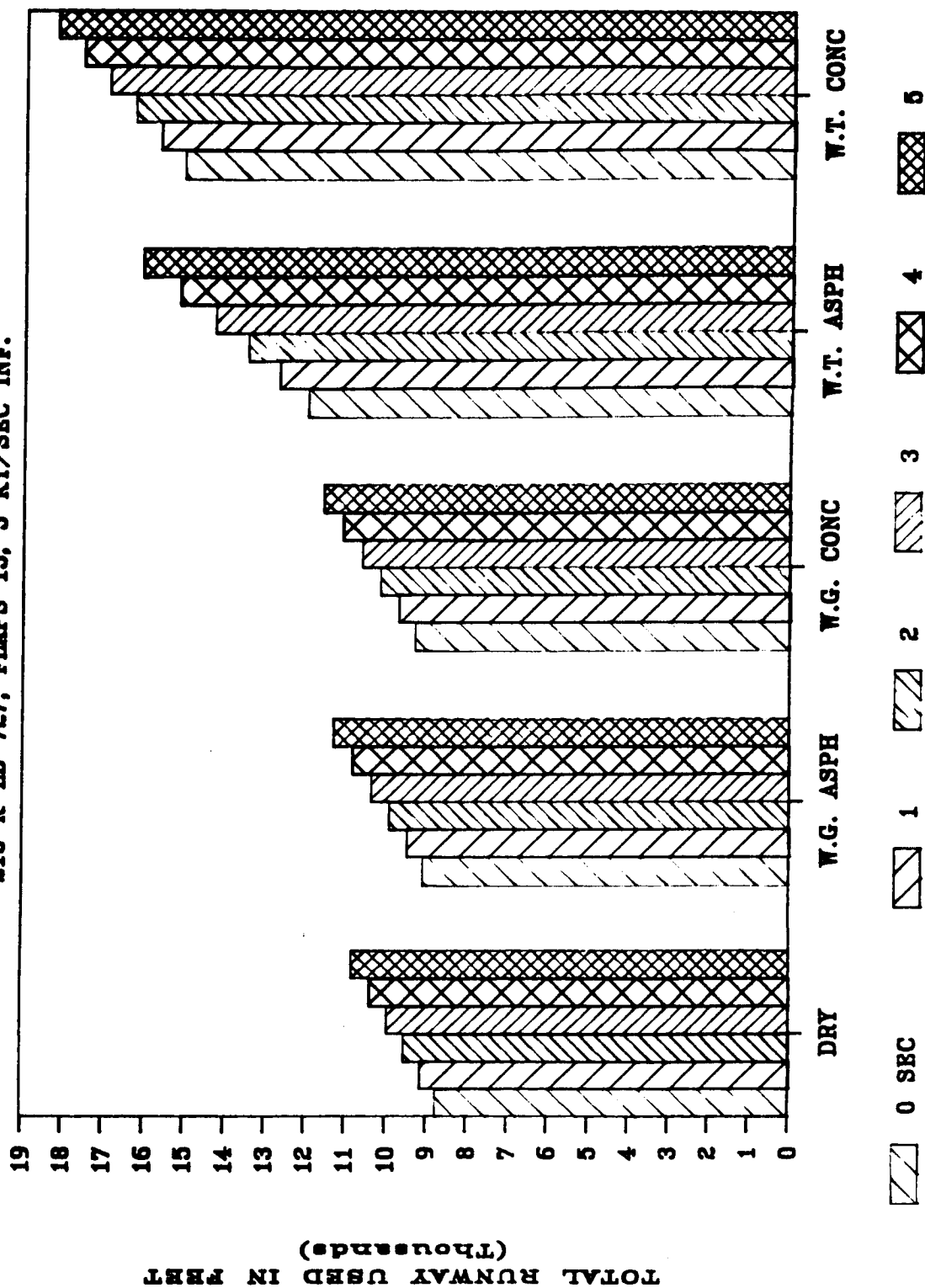
Session II. Airborne–Flight Management

Wind Shear Wind Model Simulator Analysis Status·
Bernard Ades, DGAC/SFACT/TU

WINDSHEAR WIND MODEL SIMULATOR ANALYSIS STATUS

■ INTRODUCTION

■ RULEMAKING STUDY ON WINDSHEAR MODELING

■ NEXT TO COME

■ INTRODUCTION

■ DGAC MISSION

■ DGAC ORGANIZATION

■ SFACT MISSION

■ SFACT ORGANIZATION

■ SFACT ENVIRONMENT

566

DGAC MISSION

UNDER THE AUTHORITY OF THE MINISTER IN CHARGE OF CIVIL AVIATION, DGAC MISSION
CONSISTS IN:

■ BRINGING INTO OPERATION NATIONAL POLICY CONCERNING

* AIR TRANSPORTATION

* CIVIL AERONAUTICAL MANUFACTURING

■ PROVIDE DIFFERENT SERVICES FOR THE BENEFIT OF USERS IN THE FIELDS OF:

* AIR NAVIGATION

* AIRPORT BASIC EQUIPMENT

* TECHNICAL CONTROL AND AERONAUTICAL EDUCATION

DGAC ORGANIZATION
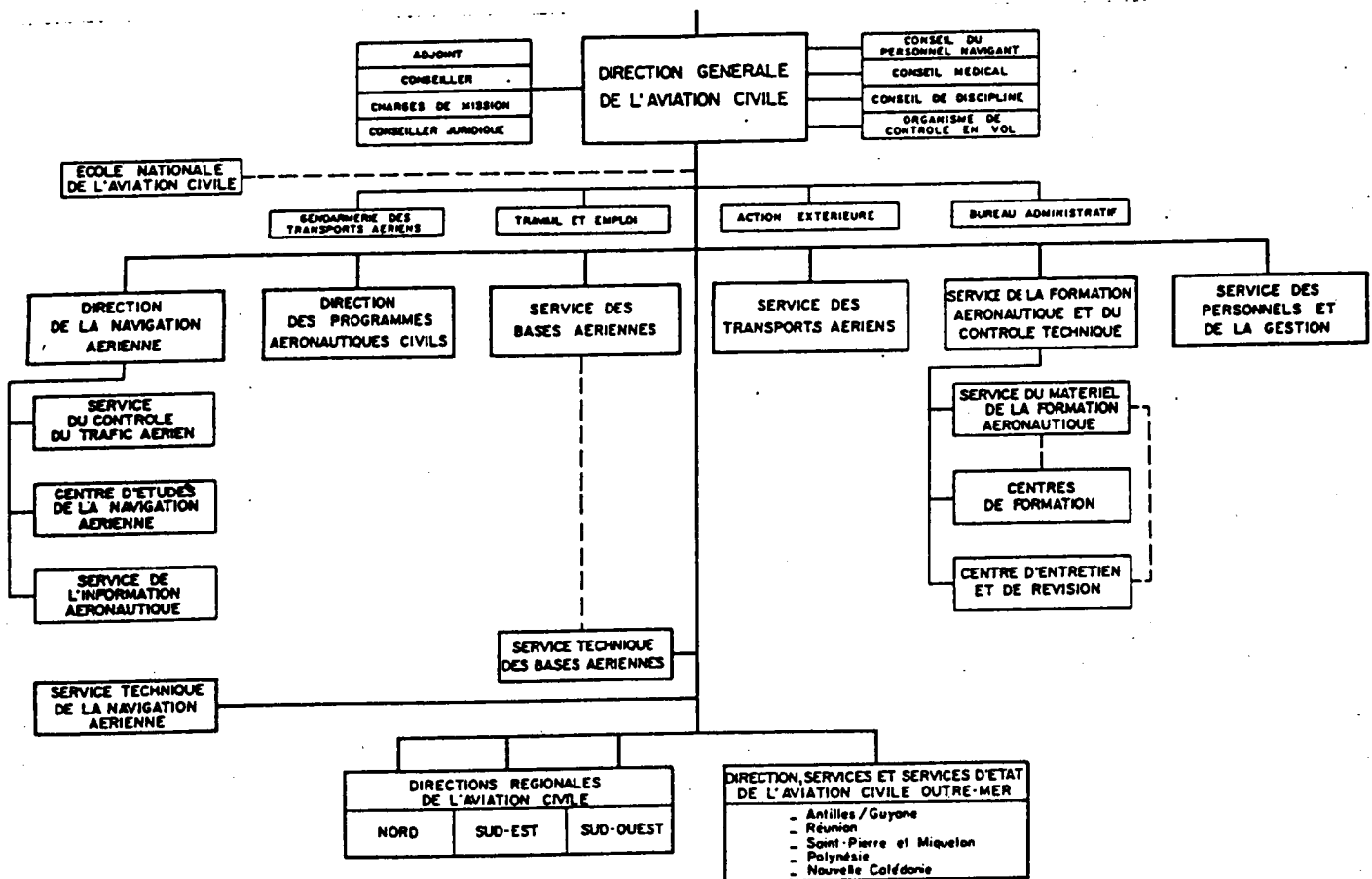
SFACT MISSION

- **THE AIM OF THIS MISSION IS THE AIRCRAFT SAFETY**

- **MEANS TO REACH THIS OBJECTIVE ARE:**

    * FLIGHT CREW RULEMAKING, RECRUITING AND PRACTICAL EDUCATION

    * GENERAL AVIATION DEVELOPMENT ORIENTATION BY HELPING FLYING CLUBS, AERONAUTICAL ASSOCIATIONS

    * DEFINITION OF AIRCRAFT SAFETY RULES AND SURVEILLANCE OF HOW THEY ARE PUT INTO OPERATION

    * TUTELAGE OF BUREAU VERITAS AERONAUTICAL ACTIVITY

SERVICE DE LA FORMATION AERONAUTIQUE ET DU CONTROLE TECHNIQUE

M. PALAYRET / M. BOMMIER / M. FRANTZEN	CHEF DE SERVICE ADJOINTS (1)
M. GUILLOU	JURY DES EXAMENS
M. CHABAGNO	CHARGE DE MISSION
M. BRUNET	INSPECTION DU PERSONNEL NAVIGANT
M. BOMMIER	SOUS-DIRECTION FORMATION AERONAUTIQUE
M. DE VILLOUTREYS	CHARGE DE MISSION
M. COLLOT	CHARGE DE MISSION
M. SANSOVINI	REGLEMENTATION DU PERSONNEL NAVIGANT
M. DEBIESSE	FORMATION ET EXAMENS DU PERSONNEL NAVIGANT
M. BOUFFARD	PROGRAMMES ET MISSIONS DES CENTRES
M. NOBEL	AVIATION GENERALE
L.C. SAINT-MICHEL	BUREAU MILITAIRE
M. PELTIER	LICENCES ET REGISTRES DU PERSONNEL NAVIGANT
M. FRANTZEN	SOUS-DIRECTION AFFAIRES TECHNIQUES
M. COFFIN	REGLEMENTATION DES AERONEFS
M. LAPASSET	CERTIFICATION DES AERONEFS
M. N'GUYEN	ENTRETIEN DES AERONEFS
M. GOUET	UTILISATION DES AERONEFS
M. DO TRINH	SYNTHESE COMPAGNIE
M. CHARPENTIER	AFFAIRES INTERNATIONALES
Mme BESSE	DIVISION ADMINISTRATIVE
M. GRANDSIRE	BUDGET
M. QUERE	PERSONNEL
	SERVICE DU MATERIEL DE LA FORMATION AERONAUTIQUE
	CENTRES ECOLES
	CENTRES NATIONAUX
	CENTRE D'ENTRETIEN ET DE REVISION

■ RULEMAKING STUDY ON WINDSHEAR MODELING

■ MAIN OBJECTIVES OF RULEMAKING STUDIES

■ CARACTERISTICS OF THE STUDY

MAIN OBJECTIVES OF RULEMAKING STUDIES

■ CERTIFICATION OF CIVIL AERONAUTICAL MATERIAL IS A FUNCTION OF FRENCH STATE

■ NECESSITY TO ELABORATE TECHNICAL RULES (AIRWORTHINESS CODE, QUALIFICATION STANDARDS, MEANS OF CONFORMITY OR INTERPRETATION TEXTES) THAT ARE RECOGNIZED BOTH BY MANUFACTURERS AND FOREIGN AUTHORITIES

■ NEED FOR LIVE RULES

■ NEED TO OPTIMIZE THE COSTS OF NECESSARY JUSTIFICATION

CARACTERISTICS OF THE STUDY

■ NOTIFICATION OF THE STUDY BY A CONTRACT BETWEEN DGAC/STPA AND
  AEROSPATIALE/CEV SIGNED AT THE END OF YEAR 87

■ OBJECTIVE OF THE STUDY IS TO DEFINE AN ACCEPTABLE SET OF WINDSHEAR MODEL FOR
  CERTIFICATION PURPOSES (SATISFACTORY MEANS OF COMPLIANCE)

■ STRUCTURE OF THE STUDY CONSISTS IN:

  * A COMPARATIVE THEORETICAL STUDY BY AEROSPATIALE

  * A COMPARATIVE SIMULATOR STUDY BY AEROSPATIALE WITH HELP OF CEV

COMPARATIVE THEORETICAL STUDY

IT CONSISTS OF A CHOICE AMONG DIFFERENT WINDMODELS PRESENTLY AVAILABLE:

* AC 20-57A AND AC 120-41

* FAA RD 74-206

* HISTORICAL GRADIENTS

* RAE DETERMINIST DOWNBURST

* RAE NON DETERMINIST DOWNBURST

* JAWS 01-85

AFTER EXAMINATION OF:

* BANDE WIDTH

* TURBULENCE STANDARD DEVIATION LEVEL

* FIELD LENGTH COMPARED TO COMPUTER CAPACITY

CHAMP N°4
AC 120.41

PISTE

pieds

X pieds

5000

1000

500

0

10 Kts

de face
en approche

arrière en
décollage

vers le
bas

PL1

CHAMP N°6
Ac 120-41

PL 2

577

CHAMP N°10
AC 12041

578

PL6
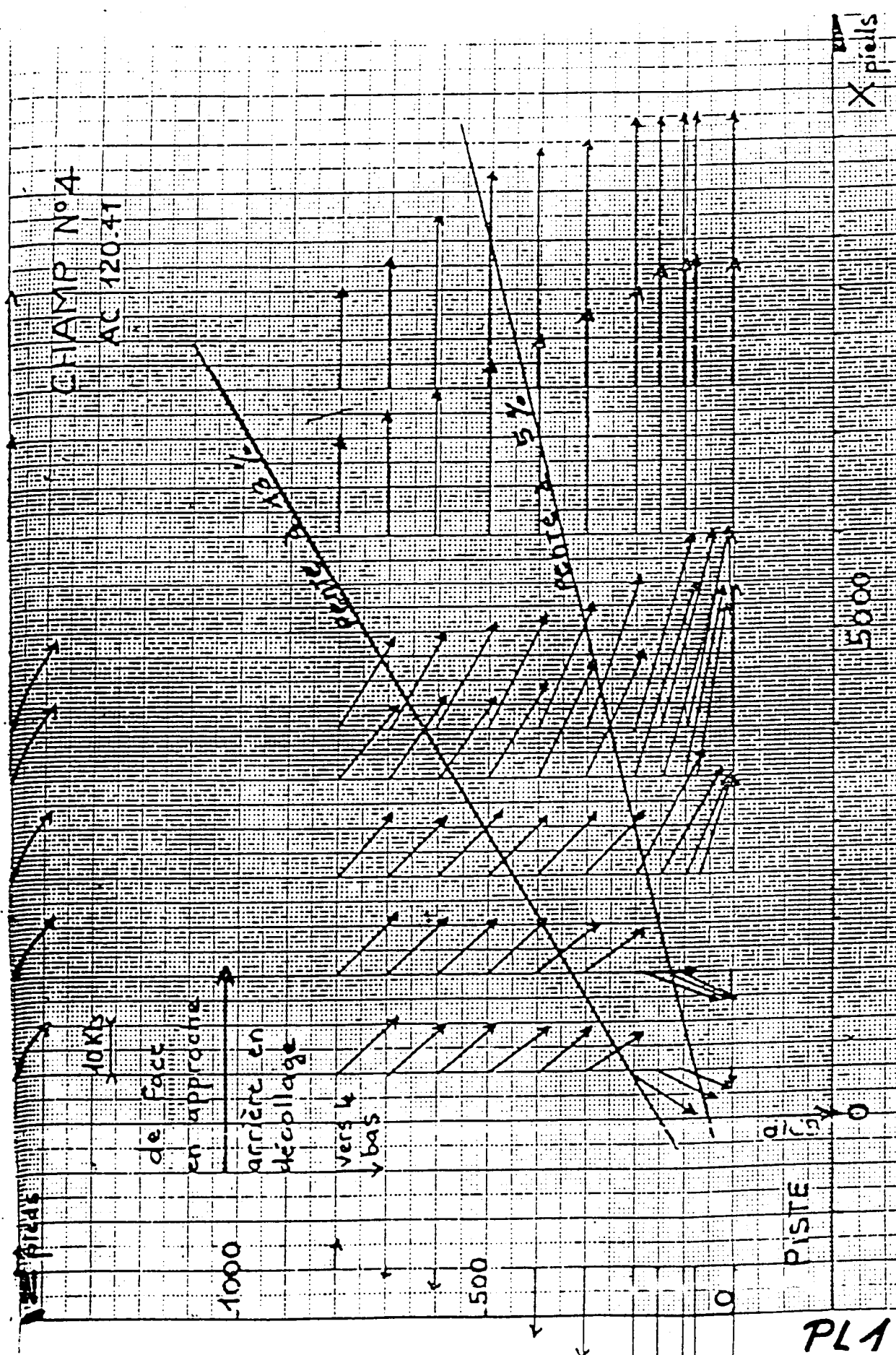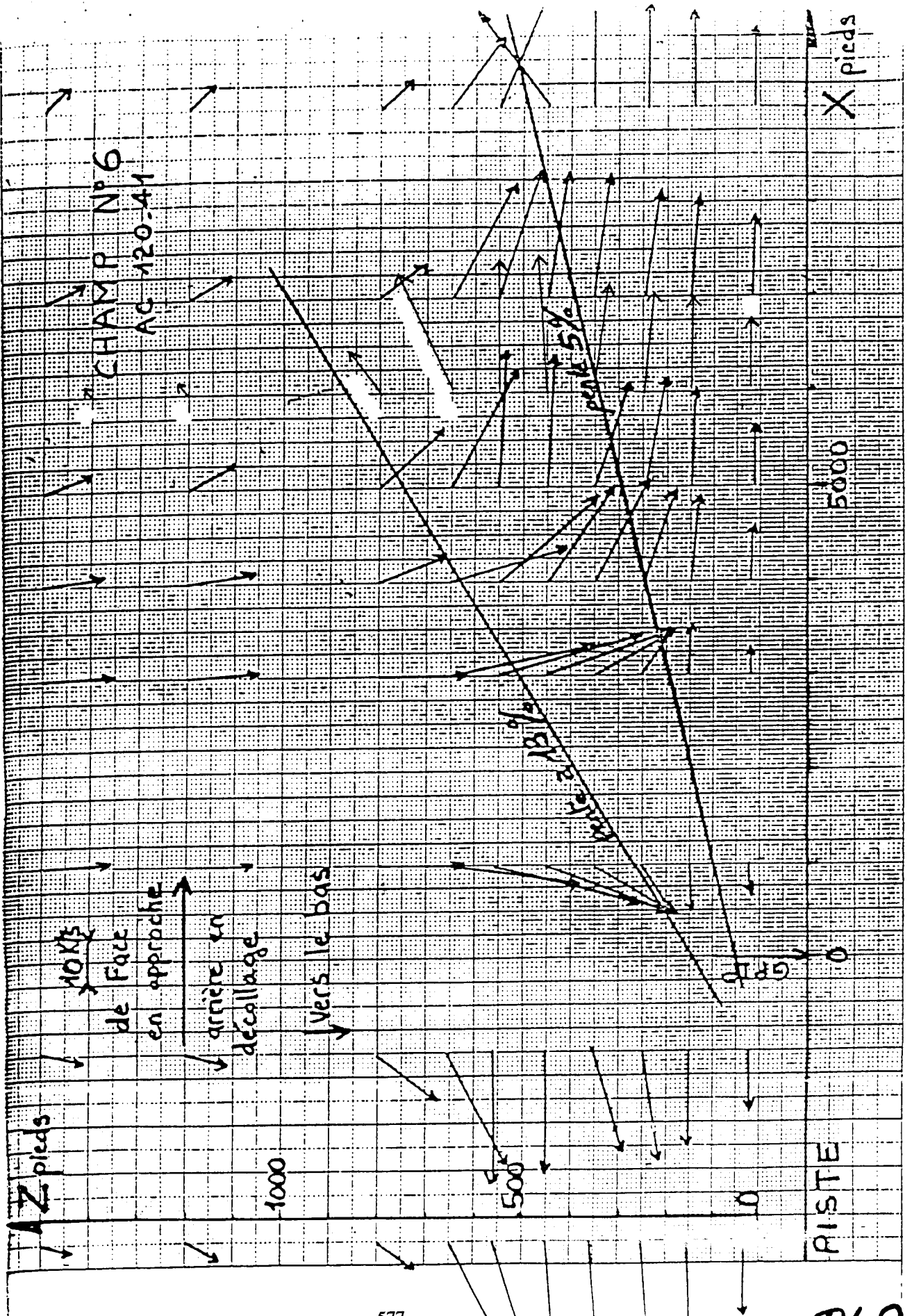
VITESSE VARIABLE

VITESSE = +140. KT ; AC-120-41 ; CHAMP = +4.

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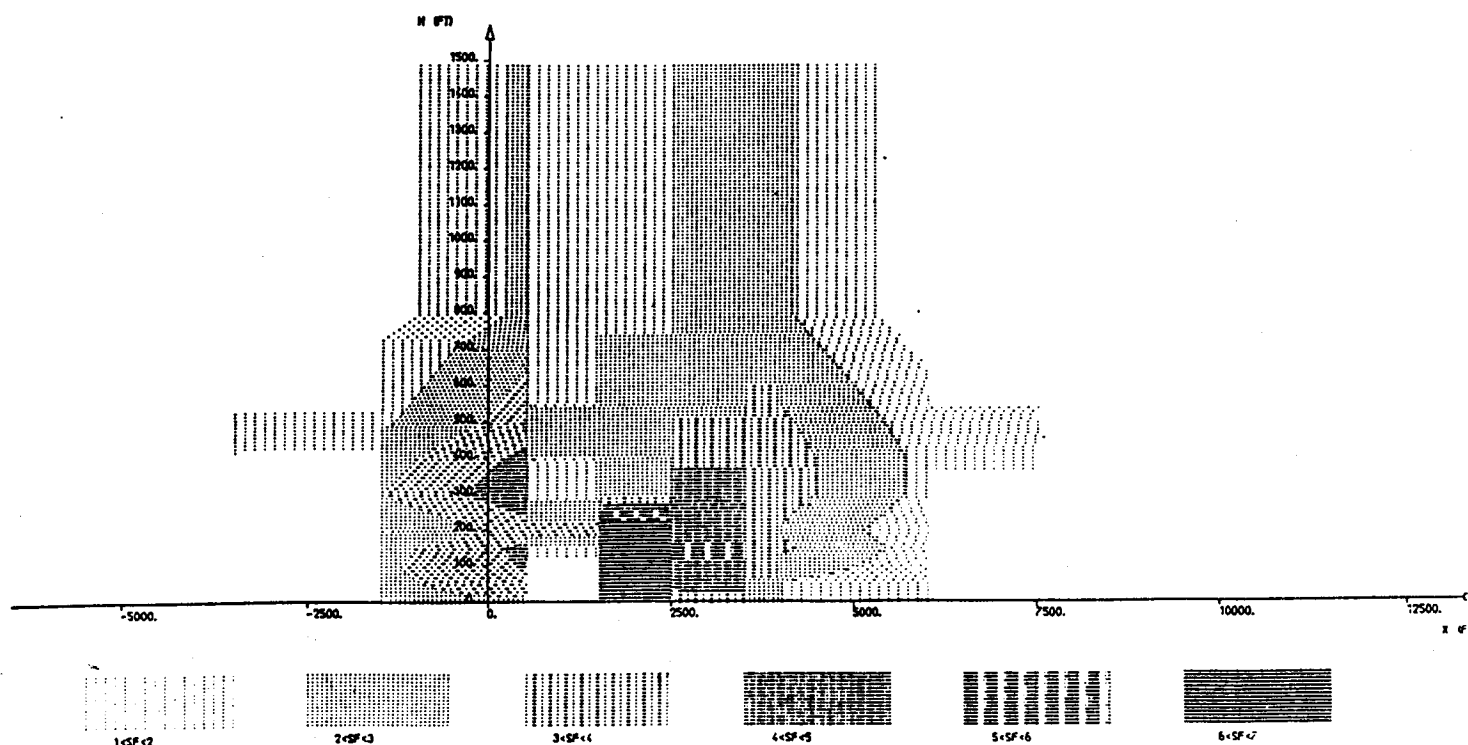| IDENTIFICATION	SEVERE A BASSE ALTITUDE	SEVERE A HAUTE ALTITUDE
AC-120-41 champ 4	+ + + +	+ +
AC-120-41 champ 6	+ + + +	+ + + +
AC-120-41 champ 7	-	+
AC-120-41 champ 9	+	+
AC-120-41 champ 10	+ + + +	+ + + +
HISTORIQUE CO 426 DEN	+ + + +	-
HISTORIQUE UAL 209 ORD	+ + + +	-
HISTORIQUE EA 66 JFK	+ + + +	+ + + +
HISTORIQUE DAL 191 DFW	+ + + +	+ + + +
HISTORIQUE TWA 524 LGA	+ + + +	-
HISTORIQUE EA 693 ATL	+	+ +
HISTORIQUE PA 759 MSY	+ + +	-
JAWS AUGUST 5, 1982, 18h45 along-path AB	+	+
JAWS AUGUST 5, 1982, 18h45 along-path CD	-	+
JAWS AUGUST 5, 1982, 18h45 along-path YZ	-	+
JAWS AUGUST 5, 1982, 18h45 along-path IJ	-	-
JAWS AUGUST 5, 1982, 18h45 along-path KL	+ + +	-
JAWS AUGUST 5, 1982, 18h45 along-path GH	-	+
JAWS AUGUST 5, 1982, 18h47 along-path AB	-	+ +
JAWS AUGUST 5, 1982, 18h47 along-path CD	-	-
JAWS AUGUST 5, 1982, 18h47 along-path YZ	-	+ +
JAWS AUGUST 5, 1982, 18h47 along-path IJ	+	+
JAWS AUGUST 5, 1982, 18h47 along-path KL	-	-
JAWS AUGUST 5, 1982, 18h47 along-path GH	-	-
JAWS AUGUST 5, 1982, 18h50 along-path AB	-	-
JAWS AUGUST 5, 1982, 18h50 along-path CD	-	+
JAWS AUGUST 5, 1982, 18h50 along-path YZ	+	-
JAWS AUGUST 5, 1982, 18h50 along-path IJ	+	+ +
JAWS AUGUST 5, 1982, 18h50 along-path KL	-	-
JAWS AUGUST 5, 1982, 18h50 along-path GH	-	-
JAWS AUGUST 5, 1982, 18h52 along-path AB	. +	+
JAWS AUGUST 5, 1982, 18h52 along-path CD	+	+ +
JAWS AUGUST 5, 1982, 18h52 along-path YZ	-	-
JAWS AUGUST 5, 1982, 18h52 along-path IJ	-	-
JAWS AUGUST 5, 1982, 18h52 along-path KL	-	-
JAWS AUGUST 5, 1982, 18h52 along-path GH	-	-

BASSE ALTITUDE : <= 500 ft   -   séverité insignifiante   + + +   séverité forte

HAUTE ALTITUDE : > 500 ft   +   séverité faible   + + + +   séverité très forte

                                    + +   séverité moyenne

Tab 10

IDENTIFICATION	SEVERE A BASSE ALTITUDE	SEVERE A HAUTE ALTITUDE
JAWS JUNE 30, 1982, 18h21 along-path EF	-	-
JAWS JUNE 30, 1982, 18h21 along-path MN	-	+
JAWS JUNE 30, 1982, 18h21 along-path PQ	-	-
JAWS JUNE 30, 1982, 18h21 along-path RS	-	-
JAWS JUNE 30, 1982, 18h23 along-path EF	-	-
JAWS JUNE 30, 1982, 18h23 along-path MN	-	+
JAWS JUNE 30, 1982, 18h23 along-path PQ	-	-
JAWS JUNE 30, 1982, 18h23 along-path RS	-	-
JAWS JUNE 30, 1982, 18h26 along-path EF	-	-
JAWS JUNE 30, 1982, 18h26 along-path MN	-	+ +
JAWS JUNE 30, 1982, 18h26 along-path PQ	-	-
JAWS JUNE 30, 1982, 18h26 along-path RS	-	-
JAWS JULY 14, 1982, 14h52 along-path TU	-	+
JAWS JULY 14, 1982, 14h52 along-path VW	-	+ +
JAWS JULY 14, 1982, 14h52 along-path OX	-	+ +
JAWS JULY 14, 1982, 14h52 along-path LS	-	+

BASSE ALTITUDE : <= 500 ft

.HAUTE ALTITUDE : > 500 ft

- séverité insignifiante
+ séverité faible
+ + séverité moyenne
+ + + séverité forte
+ + + + séverité très forte

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Tab 11

■ ON A COMPUTER

■ ON A FBS A300-600 WITHOUT ENVIRONMENT AND CABIN MOTION, DETECTION OF WINDSHEAR BEING COMPLETED BY OBSERVATION OF TENDANCY BARS OF SPEED VECTOR

■ PLUS A STUDY ON A CEV SIMULATOR (CALLED MBS) WITH MOTION AND EXTERNAL VISUALISATION

■ **UTILIZATION OF WIND MODELS**

■ **PRELIMINARY STUDIES**

■ **RESULTS**

■ **HISTORICAL MODELS**:

* WIND PROJECTIONS ARE ONLY FUNCTIONS OF DISTANCE ALONG THE
  RUNWAY AXIS

* USE OF THESE MODELS IS ONLY POSSIBLE ALONG THE HISTORICAL TRAJECTORY

■ **OTHERS** (AC 120-41, JAWS 01-85, THEORETICAL DOWNBURST)

* WIND PROJECTION ARE ONLY FUNCTIONS OF DISTANCE ALONG THE RUNWAY AXIS AND
  HEIGHT ABOVE RUNWAY

* THIS MEANS THAT MORE THAN ONE TRAJECTORY ARE FEASIBLE, ESPECIALLY FOR
  TAKE-OFF

■ **SPECIFIC TRAJECTORIES**:

* BETTER THAN NOTION OF FIELDS WOULD BE AIRCRAFT TRAJECTORIES THROUGH THOSE
  FIELDS

■ **OBJECTIVES**:

* THE AIM IS TO DETERMINE HOW TURBULENCE ON ONE SIDE, HOW THE MEANS OF SIMULATION ON THE OTHER SIDE, HAVE AN IMPACT ON THE CREW BEHAVIOUR AND ON THEIR JUDGMENT

* THIS MEANS

  - ACQUIRE A PRACTICAL EXPERIENCE ON THE MEANS

  - REDUCE THE TOTAL NUMBER OF TESTS BY DEFINING IDEAL CONDITIONS OF TESTING

■ **CONDITIONS OF TESTING**:

* FOR DETECTION, NO ALARM IS PROVIDED

* FOR ESCAPE, AN ALARM IS DEFINED BY A DISTANCE, IN ORDER TO AVOID TOO LARGE A DISPERSION OF THE POINTS WHERE ESCAPES ARE PERFORMED

* BEFORE EACH TEST, CONDITIONS ARE SET UP

* AFTER EACH TEST, THE CREW FULLFILLS A QUESTIONARY

QUESTIONARY ON WIND MODEL QUALIFICATION

1. DETECTION

1.1.

    a) With alarm: depending of the piloting informations provided, do you think the alarm has appeared:

        1 - too soon

        2 - on time

        3 - too late

    b) Informations being used for detection: (instruments, external, visualisation, motion...)

1.2. Entering the gradient (just before applying escape procedure), the situation has appeared:

    A (very critical): immediat danger, necessary reaction to be very urgent;

    B (critical)   : actual danger, necessary reaction to be urgent;

    C alarming)   : forecasted danger; the degradation of the performance, although non critical, is unacceptable

    D (abnormal)   : but not alarming; the degradation of the performance is acceptable;

    E (normal)   : comparable to a current variation of the wind;

2. ESCAPE

2.1. Piloting capacity during escape:

    a) longitudinal: ease of procedure θ - 17°5

        A: very difficult

        B: difficult

        C: mean difficult

        D: little difficult

        E: easy

    b) lateral: influence of the lateral shear on the longitudinal procedure:

        A: very disturbing

        B: disturbing

        C: little disturbing

        D: very little disturbing

        E: unexistant

2.2 Global crew workload (data surveillance...)

        A: very high

        B: high

        C: reasonable

        D: mean

        E: normal

2.3. Duration feeling in relation with the concentration effort

       A: very long duration

       B: long duration

       C: mean duration

       D: short duration

       E: very short duration

2.4. Uncapacity feeling during escape manoeuver (short term)

       A: very high, parameters within the critical zone, situation getting worse

       B: high, parameters within the critical zone, stable situation

       C: mean, parameters within the critical zone, situation getting better

       D: low, abnormal but not critical values of V1 and V2

       E: nul

2.5. Danger feeling durind escape manoeuver (danger being ground proximity or stall)

       A: very high

       B: high

       C: mean

       D: low

       E: nul

RESULTS

■ LIMITS

* AIRCRAFT MODEL

* FLIGHT CONTROLS

* PSYCHOLOGICAL ASPECT

* DIFFERENT WAYS OF PILOTING THE PHENOMENOM

* MOVEMENT

* TURBULENCE

■ ENVIRONMENT CONDITIONS IMC/VMC

■ EFFECT OF TURBULENCE

■ INSTRUMENTATION

■ NEXT TO COME

■ FROM THE STUDY

* FINALIZATION OF AEROSPATIALE RESULTS

* UTILIZATION OF A HUD

* BI-TURBOPROPELLER SIMULATION

■ OTHER STUDIES

* DEFINITION OF AN ACCEPTABLE MEANS OF COMPLIANCE FOR A DETECTION AND GUIDANCE
  EQUIPMENT

* OPERATIONAL RULES ASSESSMENT WITH AND WITHOUT AUTOMATIC GUIDANCE SYSTEM FOR
  A300/A300-600/A310/A320

Session II. Airborne–Flight Management

Wind Shear Predictive Detector Technology Study Status
C. Gandolfi, DGAC/STNA/3E

****
*   *
* **Wind Shear Predictive Detector Technology Study Status**   * 527369
*   *
****

*Presentation of French Civil Aviation Technical Service
(C.GANDOLFI from DGAC/STNA/3E).*
at

*Second Combined Manufacturers' and Technology Airborne
Wind Shear Review Meeting, Williamsburg October 18-20, 1988*

I) Introduction :

Among the different elements to be investigated when considering the Wind Shear hazard, STNA/3E [1], whose task is to participate in the development of new technologies and equipments, focused its effort on airborne and ground sensors for the detection of low-level wind shear.

The first task, initiated in 1986, consists in the evaluation of three candidate technics for forward-looking sensors : LIDAR (Light Detection And Ranging), SODAR (Sound Wave Detection And Ranging) and RADAR.

No development is presently foreseen for an infrared based air turbulence advance warning system although some flight experiments took place in the 70's. A Thomson_CSF infrared radiometer was then installed on an Air France Boeing 707 to evaluate its capability of detecting clear air turbulence. The conclusion showed that this technic was apparently able to detect clouds layers but that additional experiments were needed; on the other hand, the rarity of the phenomenon and the difficulty to operate on a commercial aircraft were also mentionned.

II) LIDAR program :

Laser technology is the only one that is presently studied for an airborne forward-looking sensor.

1) **The first step of the LIDAR program** consisted in a preliminary contract with the CROUZET company. This task initiated in may 1987 was completed by february 1988.

It consisted in the following elements :
   *investigation of operational objectives in terms of functional specifications and system design requirements : altitude and range of measurement, speed range, environmental constraints (weather, installation, ...), ...

*ground experiments with an existing mock-up sponsored by military contracts for anemometry purposes. This equipment is based on a continuous laser beam (10,6 µm), with a 75 mm telescope focusing between 10 and 100 m; the speed sign can be detected and measures around zero (± 0,25 m/s) are possible.
*evaluation for both adaptations : ground and onboard detector.

1.1 : Airborne wind shear detection :

General requirements :

The warning criteria recommended by the CROUZET company proceeds in two steps :
*a pre-alarm advisory for an increasing headwind of 40 ft/s combined with an upward vertical component;
*an alarm announce for a tailwind of 40 ft/s associated with a vertical downdraft.

The proposed technical requirements are the following ones :
*Radial speeds range from 60 to 240 knots (assuming aircraft speed between 120 and 130 knots and a wind variation of ± 60 knots);
*Velocity resolution : ± 3 knots;
*Look-ahead range of 700 m (10 s warning time) with a range resolution ≤ 300 m;
*Estimation of the vertical wind inferred from radial speed measurements in two spatially shifted locations;
*Lateral exploration by a conical scanning steered at 10° from flight path. "Left lateral", "right lateral", "up", "down" components would be delivered with an update rate of approximately 1 s;
*Environmental constraints as defined in RTCA-DO160-B.
The resulting information presented to the pilot would be the radial velocity (V_x) ,an estimation of the vertical component (V_z) and the lateral shifting of the perturbation (V_x right and V_x left).

Two technologies are proposed by the CROUZET company :
*at first, a mock-up based on a continuous CO_2 laser source (10,6 µm) with a MTBF (Mean Time Between Failure) of 1000 hours;
*in the future, for operational systems, a solid-state laser (2,1 µm) with a MTBF of 5000 hours, an half size optical diameter, a classical thermal regulation.

Future studies proposals :

*The first idea was to proceed with flight experiments of the existing mock-up where a 200 mm telescope would have been adapted in order to focus at 570 m (measurement volume between 420 m and 720 m) using conical scanning of 1 s and beam steering of 10°. The aim was to collect data on V_x laser, V_z laser, the difference between laser speed and aircraft speed, and spectra. This program didn't appear efficient enough since the technological options were not clearly defined at this stage. It seemed necessary to precisely identify the theoretical environment before carrying out expensive flight tests.

*Consequently, a second program plan was considered on the basis of flight tests supported by theoretical tasks and simulations. However, since the main technological choices (type of laser, optical diameter, ...) had to be fixed through simulation investigations, it was decided to delay the experimental phase.

The preliminary theoretical part was delegated to the ONERA research laboratory [2] because of its experience in detectors, aircraft simulators, aerodynamics, and its relationships with meteorologists as well as with people from the National Flight Test Center "CEV" [3]. Another point is that an equivalent method combining a theoretical part carried out by a research center and a realization through a mock-up designed by a manufacturer proved successful for the anemometry prototype (cooperation ONERA/CROUZET).

ONERA program plan :

The contract concerning the ONERA participation is presently to be debated but preliminary guidelines have been identified in terms of an initial study to start with. It concerns :
*the windshear models :
   -implementation of the existing FAA models
   -adaptation of new parameters specific to laser detection such as variations of the backscattered signal, absorption, rain and fog attenuation, ...
*simulations with different types of laser sensors : continuous CO_2 source with or without modulation, pulsed laser, optical diameter, ...

1.2 : Ground-based wind shear detection :

General requirements :

The operational requirements as defined by CROUZET assume a coverage until 1000 ft that is considered to be the minimum safe altitude to monitor take-off (6°) and landing (3°) flight paths.

From the various constraints (length and width of runway, lateral shifting of microburst, warning time of 10 s), a minimum range of 7,5 Km is required for a ground sensor located at the center of the runway and alternatively

scanning departure and arrival flight paths. According to the cost and availibility of technology, an alternate solution can consist of two systems focusing at 2400 m (measurement volume between 40 m and 3400 m). The spatial resolution must be better than 300 m for a range of speed of ± 60 knots with a speed resolution of ± 3 knots.

Among the constraints, the environmental severity factor must be taken into account : electrical protection, temperature (-30°C/60°C), humidity, sand and dust, salt spray, ... The foreseen MTBF is 5000 hours.

Another essential aspect is that in order to be efficient, a ground-based equipment needs an automatic alert transmission.

Ground-based experiments :

The equipment is based on a continuous laser source (10,6 µm), with a 75 mm telescope focusing between 10 and 100 m. However, in order to increase the range, some measurements were done at 200 m ([50m, 350m]).

Preliminary tests were settled in CROUZET facilities in order to observe building-induced turbulence. Despite CROUZET conclusions, this experiment didn't prove demonstrative since the collected values didn't show a sufficient amplitude dynamic (0 to 4 m/s).

The first set of tests consisted of :
-preliminary measurements with a fixed mirror and focusing distance of 35 m;
-conical scanning : beam steering at 15° orientation and 40 rounds per minute for a focusing distance of 200 m. The theoretical graph is a sinusoid whose mean value depends on the wind component along line of sight. The amplitude is a function of the perpendicular component module; the phase is related to its orientation. Wind field dispersion distorts the ideal curve.
Several rotation speeds were experimented. Since the angular shifting of line of sight cannot be omitted any longer during the acquisition of instantaneous spectra for one measurement, the spectrum width increases with the rotation speed.
-measurements in rain conditions : the spectrum enlarges because of rapidly changing speeds of turbulence and rain. In some experiments, rain drops speed signal was more powerful than wind speed itself.

The system was then installed on the military base of Valence. The frequent proximity of helicopters at low altitude gave the opportunity to collect data on turbulence engendered by their rotor blades.
-variation of the focusing distance from 30 m to 200 m showing the spectrum spreading at "long distance".

-measurement volume splitting by putting a mirror on the line of sight in order to demonstrate the capability of indicating the change of sign in velocity.

Future studies proposals :

The pulsed technique is the only valid candidate for the 7,5 Km range criteria. Furthermore, it guarantees a spatial resolution propotional to the pulse length and light celerity. Since ground clutter isn't a sensitive point, a slight deviation of laser beam (2° tilt) could be used to evaluate phenomenon shifting.

An alternate solution,proposed by CROUZET, is to use two equipments located at 2400 m from each runway extremity and monitoring a smaller zone : 40 m to 3400 m. This system would be based on a continuous laser with adaptative focusing distance. A 30 cm telescope would be used in order to conciliate cost constraints and atmospheric turbulence effects. The spatial resolution rapidly deteriorates with distance. According to CROUZET, a measurement could be correctly located for distances up to 1 Km and beyond detection would still be possible for spread and quite homogeneous phenomena. The idea consists in frequency coding of emission. This method was tested and validated for distances lower than 1 Km but it must be experimented for greater range since it seriouly decreases the signal to noise ratio. It could also be a mean of getting rid of undesired targets (insects, birds, ...).

1.3 : Conclusion :

The efficiency of the LIDAR technic is obviously mostly limited by attenuation due to rain, fog and by perturbations engendered by moving point clutter (birds, insects, ...).

Concerning the laser source itself, the continuous CO_2 technology is available but pulsed and solid-state lasers need further development.

In France, airborne LIDAR is also experimented for vertical wind profiles by the Dynamic Meteorology Laboratory.

Although CROUZET existing laser anemometry prototype is well adapted for anemometry purposes, it didn't appear well suited for a transformation into a wind shear detector. Furthermore, from preliminary studies, it seems more efficient to study the option of an airborne LIDAR rather than a ground-based equipment. That's why, further research work will be done by the ONERA laboratory before proceeding to the design , integration and validation of an airborne LIDAR in a flight demonstration program.

2) **The second step of the LIDAR program** is not yet defined but a preliminary study is to be started with ONERA laboratory (cf 1.1).

III) SODAR program :

1) Program objectives and methodology :

The SODAR system (developped by the REMTECH company) analyses the backscattered wave resulting from emission of sound pulses. The returned signal will be Doppler shifted in frequency by an amount proportional to the backscattering cells representative of wind velocity.

The first generation of SODARs included three horn fed dishes with one vertical antenna and the two other ones slightly vertically tilted. The whole thing was enclosed in an absorbant protecting material. This equipment had been designed to collect wind field direction and intensity in the low altitude atmosphere layers for pollution detection purposes mostly.

The aim of the contract between French Civil Aviation and Remtech Co. was to examine whether it was feasible to adapt this type of equipment for ground-based wind shear detection along take-off and landing flight paths.

The evaluation guidelines concerned :
*environmental problems : surrounding noise, influence of aircraft noise, ...;
*sound pollution generated by the equipment;
*influence of ground proximity at low tilt : noise, acoustic rays curvature, ground clutter;
*feasability of a "megasodar" supposed to reach 6 Kms by using a multicellular antenna.

The conclusion of this contract notified in may 1987 was supposed to make a comparison between directivity patterns calculated in simulations and experimental results in order to check whether it's valid to extrapolate for a multicellular antenna.

2) Program evolution :

The feeble performances of the horn fed dish antenna made it impossible to carry out all the necessary measurements. Consequently, the realization of a multicellular antenna mock-up became absolutely necessary. That's why, the priorities previously defined had to be changed. Furthermore, the bad wheather conditions of spring 1987 in Paris during the installation on Roissy airport delayed the experimental phase that is still going on.

The theoretical part consisted in test antenna optimization (2,4 m diameter horn fed dish antenna). At a given frequency, the only parameter that can be modified is the illumination function. In order to evaluate the characteristics in the far-field, directivity calculations were done by simulations for various amplitude distributions with phase locked. Obstacle effects were simulated by approximated calulations.

3) **Experimental phase** :

It was organized in three parts :
  *measurement of the antenna characteristics;
  *quantification of physical influences;
  *wind measurements.

Directivity measurements showed good agreement between theoretical and effective patterns for angles lower than 4° and an important discrepancy beyond, resulting in high sensitivity to ground clutter. It was assumed (and experimentally confirmed afterwards) that this difference was caused by the obstacle effect generated by the antenna feed (horn of 25 cm). Directivity measurements using a piezo-electric tweeter of 8 cm resulted in good agreement with theory but the improvement for ground clutter is of only 6 dB.

Despite the poor performances of the first antenna configuration (JBL antenna feed of 25 cm), some measurements series were recorded with an emission at 4000 Hz and several tilts were analyzed. It showed the important influence of temperature and humidity on atmospheric absorption. These reflectivity fluctuations induce variations of range from 290 m to 180 m.

Another testing bench with the second antenna configuration (tweeter + dish antenna) showed that, despite the ground clutter elimination algorithm, in some cases, wind measurements were irrelevant. The data processing needed a manual analysis in order to guarantee good agreement with wind speeds recorded from an anemometer (from National Meteorology) located on the airport.

In order to prove "megasodar" feasibility, the REMTECH company decided to build a small-scale multicellular antenna mock-up using a rectangular array of tweeters.
The main anticipated advantages are :
  *elimination of obstacle effects;
  *independant amplitude tuning;
  *beam steering by phase shifting among the different elements;
  *increase of power (number of elements).
However, the interaction between elements hasn't been taken into account and this assumption must be checked by further experiments.

4) **Conclusion** :

The small-scale multicellular mock-up was designed to reduce complexity by minimizing the quantity of independant elements. Since the major problem concerned the vertical plane, the amplitude tuning will only be applied to the vertical section and there will be less antenna feeds on the lines than on the columns. Because of their great dispersion, the tweeters were previously tested and selected. This array is made of 392 elements with a spacing of 8.85 cm and distributed into 28 lines and 14 columns for a surface of 2.5 m x 1.25 m.

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Theoretical calculations of the estimated range were done. The multicellular mock-up will be taken up soon in order to be experimented. The success of this stage is crucial since the lack of performance of previous antenna configurations made it impossible to demonstrate the ability of this technic to detect wind shear.

IV) Ground-based RADAR program :

1) Introduction :

Wave-length is a crucial parameter for radar detection. With wave-lengths ≤ 5 cm, it's possible to design small antennas with high angular resolution (<<3°), resulting in good vertical resolution for wind profiles and a good protection against ground clutter. However, an experimental program carried out by the CRPE [4] in 1985 showed that this type of radar couldn't correctly measure in clear air condition. It was theoretically concluded that, in order to operate in clear air as well as in rain conditions, for a radar of 4.5 Kw peak power equipped with a 5 m antenna, the optimal bandwith ranged from 20 to 35 cm.

The laboratory designed a 30 cm radar (4.5 Kw peak power) for atmospheric research purposes (PROUST system). With a 11 m antenna, this equipment proved able to vertically observe the troposphere up to 10 Kms. Of course, the use of a 5 m antenna will decrease the clear air detection level of 7 dB but a compensation from the turbulent energy gain is anticipated.

Consequently, the UHF radar hold the attention as a feasible candidate in ground wind shear detection.

2) Program objectives :

An agreement was signed with CNET/CRPE [4] in order to study the feasability of wind shear detection both in clear air and rain conditions using a ground-based radar.

The aim is to perfect design criteria for a specialized radar by theoretical and experimental studies with the following operational constraints :

*radial measurement of windshear along departure and arrival flight paths;
*detection in both clear air and rain conditions;
*range : 600 m to 10 Kms;
*range resolution : ≤ 600 m;
*angular resolution : ≤ 3°;
*speed resolution : $5 \ 10^{-2} \ s^{-1}$;
*false alarm rate : < 10 %;
*moderate cost : ≤ 3 MF (≤ 600,000 $);
*peak transmission power : ≤ 5 Kw;
*antenna diameter : ≤ 5 m.

3) Program planning:

3.1 *Evaluation of 30 cm radars performances at low horizontal tilt in wind shear conditions* :

*Ground clutter calculations,
                    (July 1988);
*Wind shear models implementation on simulator,
Radar characteristics optimization,
                    (September 1988);
*Shadow effect generated by aircraft,
Simulation of radar spectra with ground clutter,
Wind profiles extraction,
                    (May 1988);
*Experimental evaluation with PROUST radar and ground clutter and aircraft signatures,
                    (May 1988);

3.2 *Evaluation of feasibility on airport* :

*Synthesis of previous tasks,
                    (November 1988);
*Additional theoretical studies and definition of an adapted antenna,
                    (May 1989);
*Measurements of wind shears and/or turbulence on airport,
                    (date not fixed);

3.3 *Conclusion* :
                    (November 1990);

4) Program evolution :

* Wind shear models (historical, AC120_41, JAWS models) were implemented and tested on CNET computer facilities for simulation. From the discontinuous distribution of wind speeds, a continuous wind field was produced by using the techniques described in the JAWS program. Radar spectrum response within a wind shear field can then be anticipated gate by gate.
* Ground clutter modelling is based on gate/ground contact surface and random distribution law of the obstacles (a hundred obstacles of 10^4 m^2 each for all the gates).
* Aircraft clutter elimination is the next point to be studied. Research work concerns :
    -antenna optimization (to be studied in 2.2 phase);
    -radar processing :
      -case of aircraft on main lobe : saturation, signal attenunation before reception, elimination algorithm;
      -case of aircraft on sidelobe : elimination algorithm with spectral signature of aircraft.

5) **Program continuation** :

5.1 *Aircraft clutter elimination* : (June 1989)
*New algorithms for elimination;
*Simulation and test of previous methods of elimination;
*Statistic study of aircraft clutter;

5.2 *Ploemeur Bodou experimentation* : (June 1989)
*Definition of experiments and schedule;
*Experiments with antenna tilted at 45°;
*Measurements analysis : experimental results of clutter elimination methods performances.

5.3 *Installation on airport* : (September 1989)
*Definition of optimal antenna : sidelobes attenuation (absorbant material, lattice-work, trench), antenna feed, radiated pattern;
*Definition of the optimal location for installation : ground clutter minimization for main lobe and first sidelobes, ground clutter map, possibility of making a trench, aircraft return reduction by carefully positionning antenna lobes in relation to taxiways, departure and arrival flight paths.

6) **Preliminary theoretical results** :

6.1 *Spectral width* :

Among the main causes of increasement of spectrum width such as distribution of scattering cells speeds, turbulent field mean quadratic speed, limited width of beam, sampling rate, non ambiguous distance, wind whear is the most contributing one, resulting in radar capability in providing relevant measurements.

6.2 *Measurement Accuracy* :

Assumption : in the elementary volume chosen for simulations (30mx30mx30m), the radial speed is supposed to be constant.

Simulation showed that for low-altitude horizontal wind shear structures (inversion layer, thermic wind) localization can be impossible for several gates. For vertical wind field distributions, the radar delivers a precise localization of the phenomenon.

Minimum reflectivity factor (Cn^2) required to guarantee a good detectability at 10 Kms was evaluated as a function of wind shear intensity per gate. Wind shear detection at 10 Kms requires an equivalent reflectivity factor Z_e of - 10 dBz for a wind difference (in a gate of 600 m) of 8 m/s ($\approx$ 16 knots) and of - 2 dBz for 30 m/s ($\approx$ 60 knots). These results do not depend on antenna aperture that can eventually modify extreme wind speed measured because of the variation of the volume observed.

6.3 *Safety requirements* :

For the pilot :
  *Detect wind shear,
  *Identify its type,
  *Quantify its intensity,
  *Localize it,
  *Anticipate its evolution;
For the tower officer :
  *Wind speed and direction,
  *Anticipation on phenomenon duration,
  *15 mn prevision of possible occurence.
(as defined by the CLAWS program).

An alert system combining radar detection and meteorology analysis is presently foreseen in order to decrease false alarm rate. At the beginning, human intervention will be necessary but automatization of the whole process needs to be developped in a further stage. High collaboration between radar operators and meteorologists is necessary to develop and fix a performant wind shear alert algorithm but meteorological research hasn't begun yet.

6.4 *Non atmposheric returns* :

High power targets may be all the more detected by the radar as the horizontal tilt of the antenna is low. These spurious echoes are a serious danger for wind shear detection since the wind tracers have got a smaller cross section. This results in two consequences :
  *saturation of radar input level,
  *superposition of two signatures of highly different power.
Main bibliographical results on efficient section influence were summarized. Spectral width increasement due to ground clutter was experimentally evaluated with PROUST radar (30 cm). The main results are the following ones :
  *phase stability at short term is crucial; it should be better than 10^{-2} Hz ($2 \cdot 10^{-3}$ m/s);
  *Doppler jitter highly varies with season (winter/summer), humidity and wind ground;
  *In order to quantify spectral increasement due to ground clutter, the increasement must be defined from the amplitude corresponding to the noise, that is the width for a signal to noise ratio taking while into account the return statistical dispersion;
  *The absolute limits variations due to multipaths, Fourier transform of a temporal limited function, echoe structure jitter range from DV = 1 m/s to 2 m/s.
Estimations of signal to clutter ratio show that it is necessary to decrease ground clutter level of 60 dB in order to guarantee atmospheric detection for the first gates. Another point is that these echoes create a Doppler zone of ± 1 m/s where wind shear detection may be difficult. A method was developped in order to detect atmospheric echoes with amplitudes and Doppler shifts lower than those typical of fixed echoes. This method makes it possible to detect atmospheric echoes with ground clutter for a signal to noise

ratio of - 30 dB and Doppler shifts of 0.25 m/s. As long as the analogic signal doesn't saturate amplification and exceed analogic/numeric converter capabililty, wind shear detection should be provided.

6.5 *Fixed echoes elimination* :

Angular and temporal filtering methods of analogic signal were investigated. The methods that are presently foreseen for the PROUST radar are :
*"distance gate MTI" (Skolnik,1981) : selection of the main spectrum line and rejection of the central zone "polluted" by fixed echoes; this technic needs phase stability to be efficient;
*adjustement of the ground model to the spectrum; this method is presently tested on the PROUST radar and makes it possible to discriminate useful and undesired echoes.
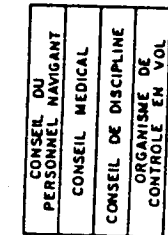
6.6 *Preliminary conclusions* :
*ground clutter dynamic : it should be suppressed by improving antenna efficiency and using numerical filtering methods.
*very law altitudes detection (<<100 m) at short distance from GPIP : a technic consisting of gates of variable length will soon be simulated for evaluation.
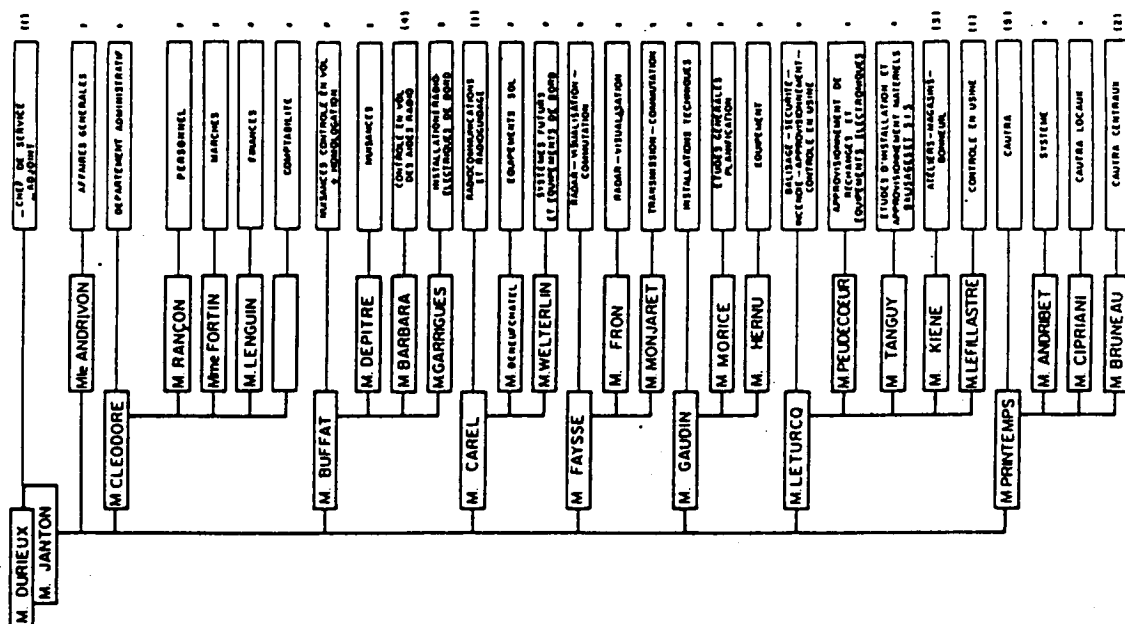

IV) **Abbreviations** :

[1] Aeronautical Navigation Technical Service (cf Annex 1)
Service Technique de la Navigation Aérienne
[2] Aerospatial Studies and Research National Office
Office National d'Etudes et de Recherches Aérospatiales
[3] National Flight Test Center
Centre d'Essais en vol (CEV)
[4] CNET : Telecommunication Research National Center
Centre National d'Etudes des Télécommunications
CNRS : Scientific Research National Center
Centre National de Recherche Scientifique
   CRPE : Environmental Physics Research Center, laboratory jointly sponsored by CNET and CNRS.
Centre de Recherche en Physique de l'Environnement

Ministère de l'équipement, du logement, de l'aménagement du territoire et des transports
Ministre délégué chargé des transports

```
                              ┌─────────────────────────┐
                              │  CONSEIL DU             │
                              │  PERSONNEL NAVIGANT     │
                              │  CONSEIL MEDICAL        │
                              │  CONSEIL DE DISCIPLINE  │
                              │  ORGANISME DE           │
                              │  CONTROLE EN VOL        │
                              └─────────────────────────┘

        ┌──────────────┐     ┌─────────────────────┐
        │  ADJOINT     │     │  DIRECTION GENERALE │
        │  CONSEILLER  │─────│  DE L'AVIATION      │
        │  CHARGES DE  │     │  CIVILE             │
        │  MISSION     │     └─────────────────────┘
        │  CONSEILLER  │
        │  JURIDIQUE   │
        └──────────────┘
```

ECOLE NATIONALE DE L'AVIATION CIVILE

GENDARMERIE DES TRANSPORTS AERIENS

TRAVAIL ET EMPLOI

ACTION EXTERIEURE

BUREAU ADMINISTRATIF

SERVICE DE LA FORMATION AERONAUTIQUE ET DU CONTROLE TECHNIQUE

SERVICE DES PERSONNELS ET DE LA GESTION

SERVICE DU MATERIEL DE LA FORMATION AERONAUTIQUE

CENTRES DE FORMATION

CENTRE D'ENTRETIEN ET DE REVISION

SERVICE DES TRANSPORTS AERIENS

DIRECTION DES PROGRAMMES AERONAUTIQUES CIVILS

SERVICE DES BASES AERIENNES

SERVICE TECHNIQUE DES BASES AERIENNES

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SERVICE DE L'INFORMATION AERONAUTIQUE

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DIRECTIONS REGIONALES DE L'AVIATION CIVILE
- NORD
- SUD-EST
- SUD-OUEST

DIRECTION, SERVICES ET SERVICES D'ETAT DE L'AVIATION CIVILE OUTRE-MER
- Antilles/Guyane
- Réunion
- Saint-Pierre et Miquelon
- Polynésie
- Nouvelle Calédonie

SERVICE TECHNIQUE DE
LA NAVIGATION AERIENNE

(1) - 246, Rue Lecourbe
75732 PARIS CEDEX 15
                                        48.28.40.20
TELEX   ----STNA----   202.887
TELECOPIE   ------------   48.56.87.20

(2) - 91205 ATHIS MONS CEDEX
                                        69.84.50.00
TELECOPIE   69.84.55.28

(3) - 31, Avenue du Maréchal Leclerc
Boîte Postale 5
94380 BONNEUIL SUR MARNE
                                        43.39.68.00
TELEX   262.200
TELECOPIE   43.99.05.09

(4) - Aérodrome de Melun-Villaroche
77550 MOISSY CRAMAYEL
                                        64.71.44.44
TELEX   692.915
TELECOPIE   64.71.43.81

(5) - 95, Rue Henri Rochefort
91000 EVRY
                                        64.97.81.11

NOTA : le "Cautra Centraux", actuellement à ATHIS-MONS (2), sera regroupé à EVRY
(5), département Cautra, en juin 1988.

Annex 1 - p 2 -
606
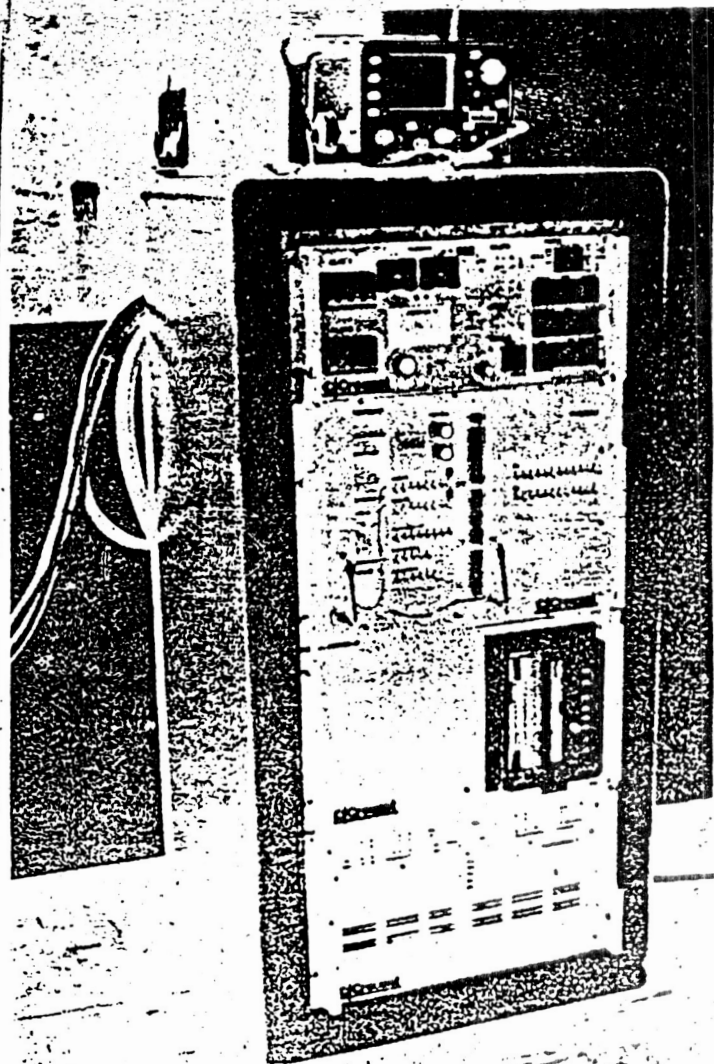
PLANCHE 1

Baie de commande
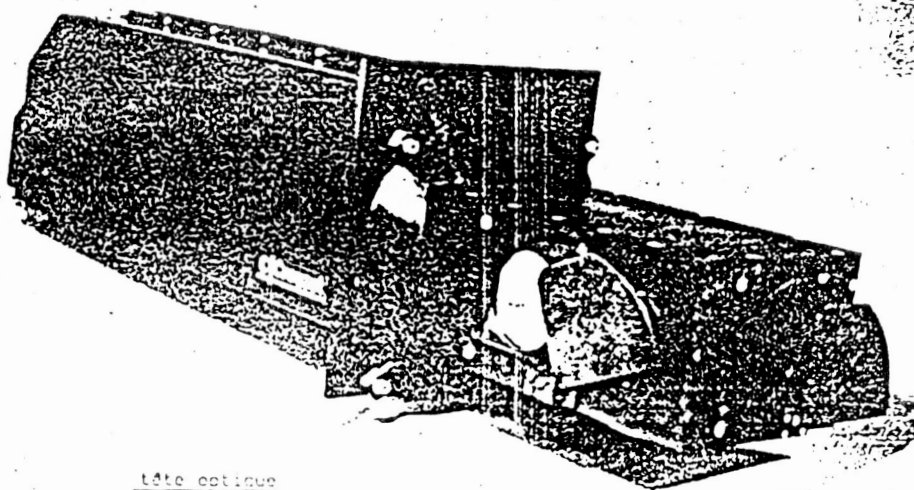
tête optique

Anémomètre à laser
pour essais en vol

Crouzet

609
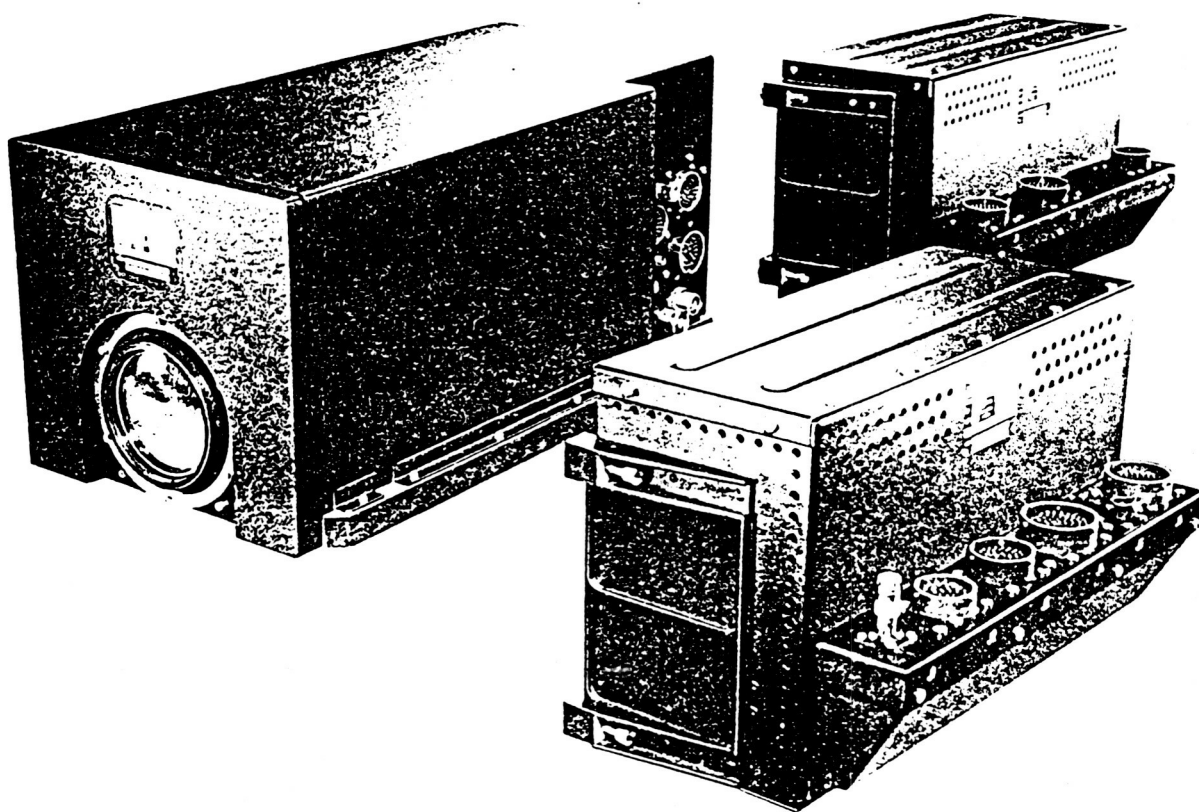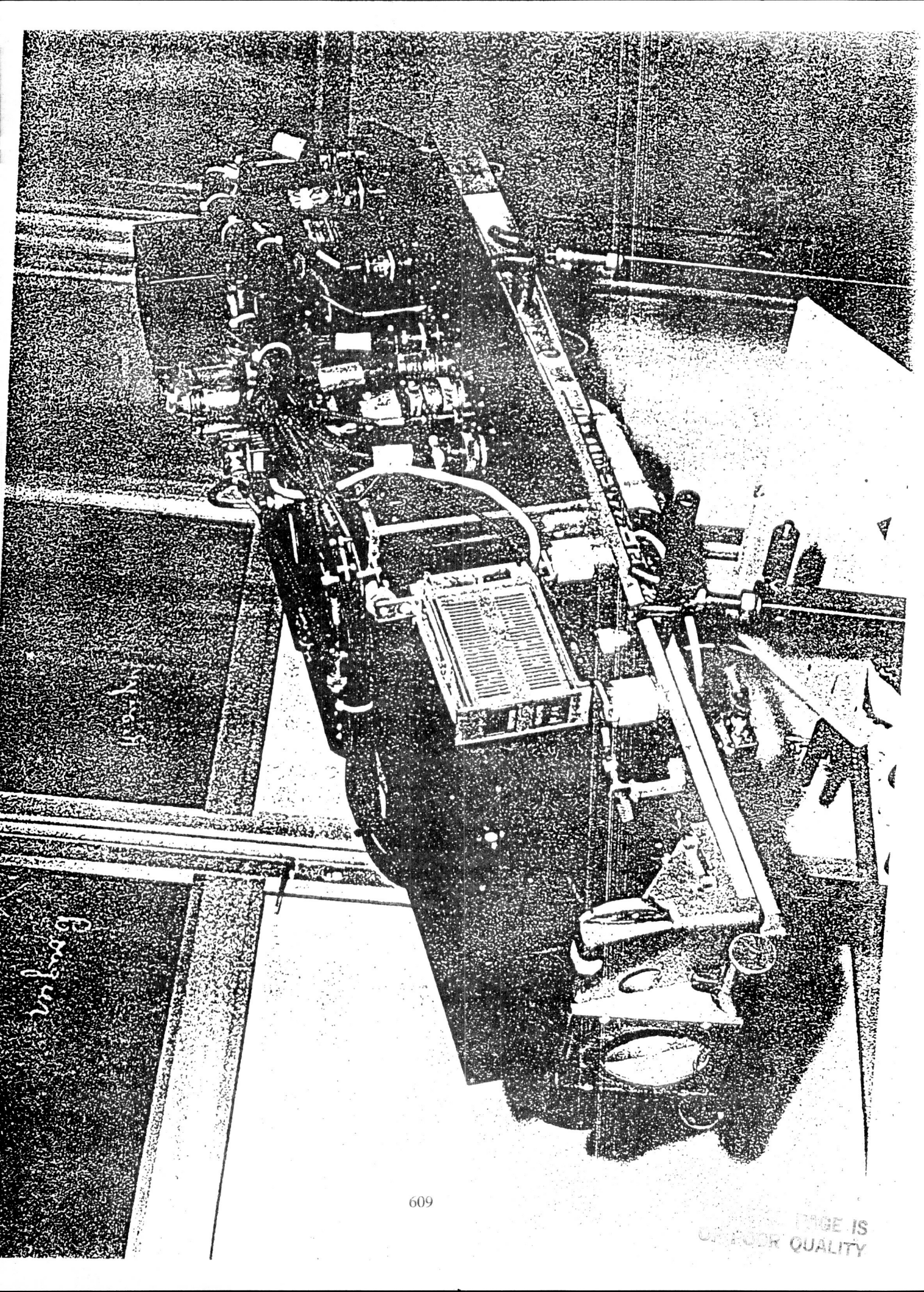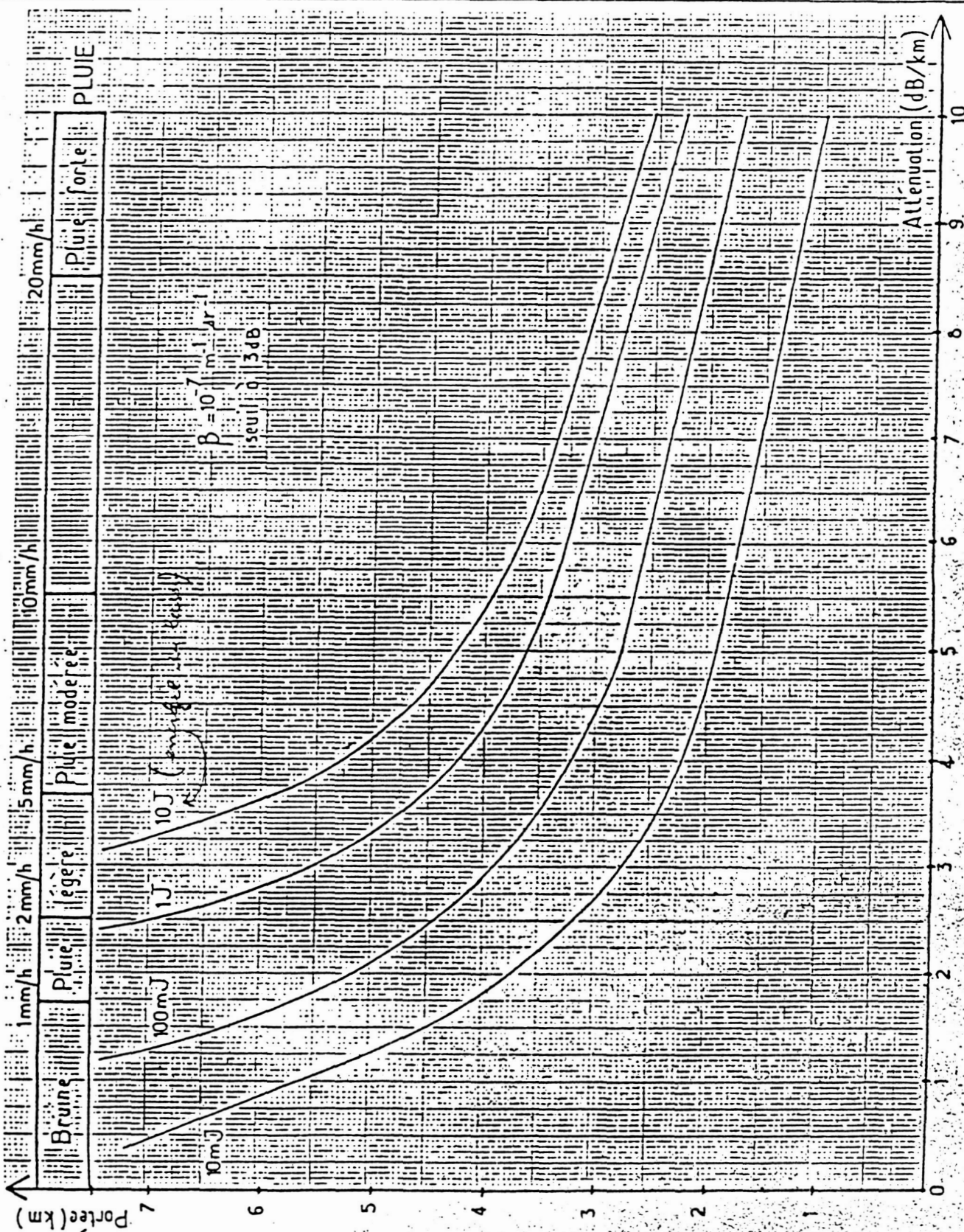
Dégradation des performances par l'attenuation

2dB |

PLANCHE 31 DATE 151087
S. MOYENNE

Effet d'un vent fort et régulier
à 200m

V (m/s)

ORIGINAL PAGE IS
OF POOR QUALITY

PLANCHE 14
ESSAIS GDV No 1
DATE 0
S.MOYENNE

2dB

T (S)

Mise au point 20m
Miroir à 20m.
=▷ volume de mesures partagé selon deux directions

V m/s
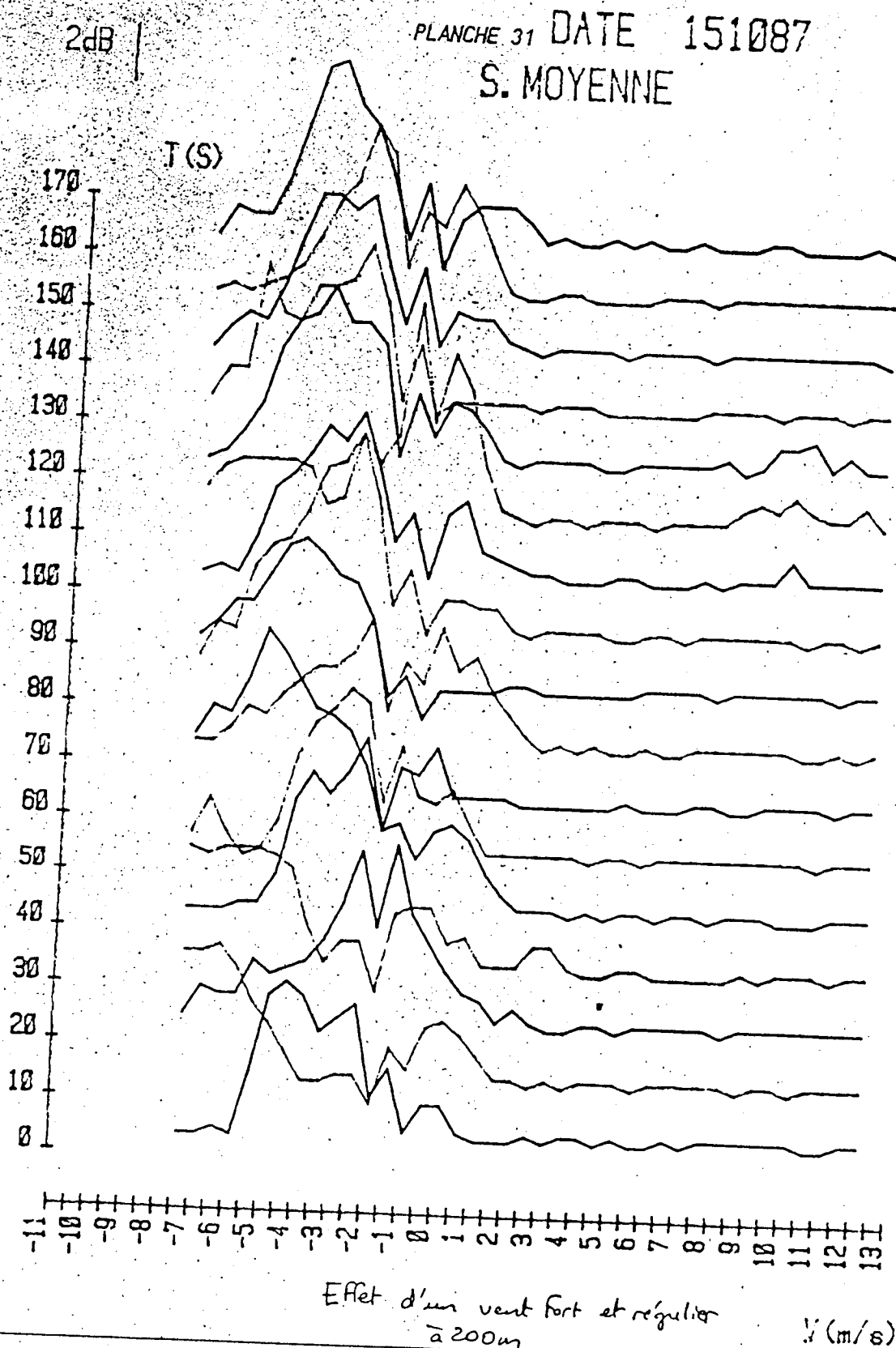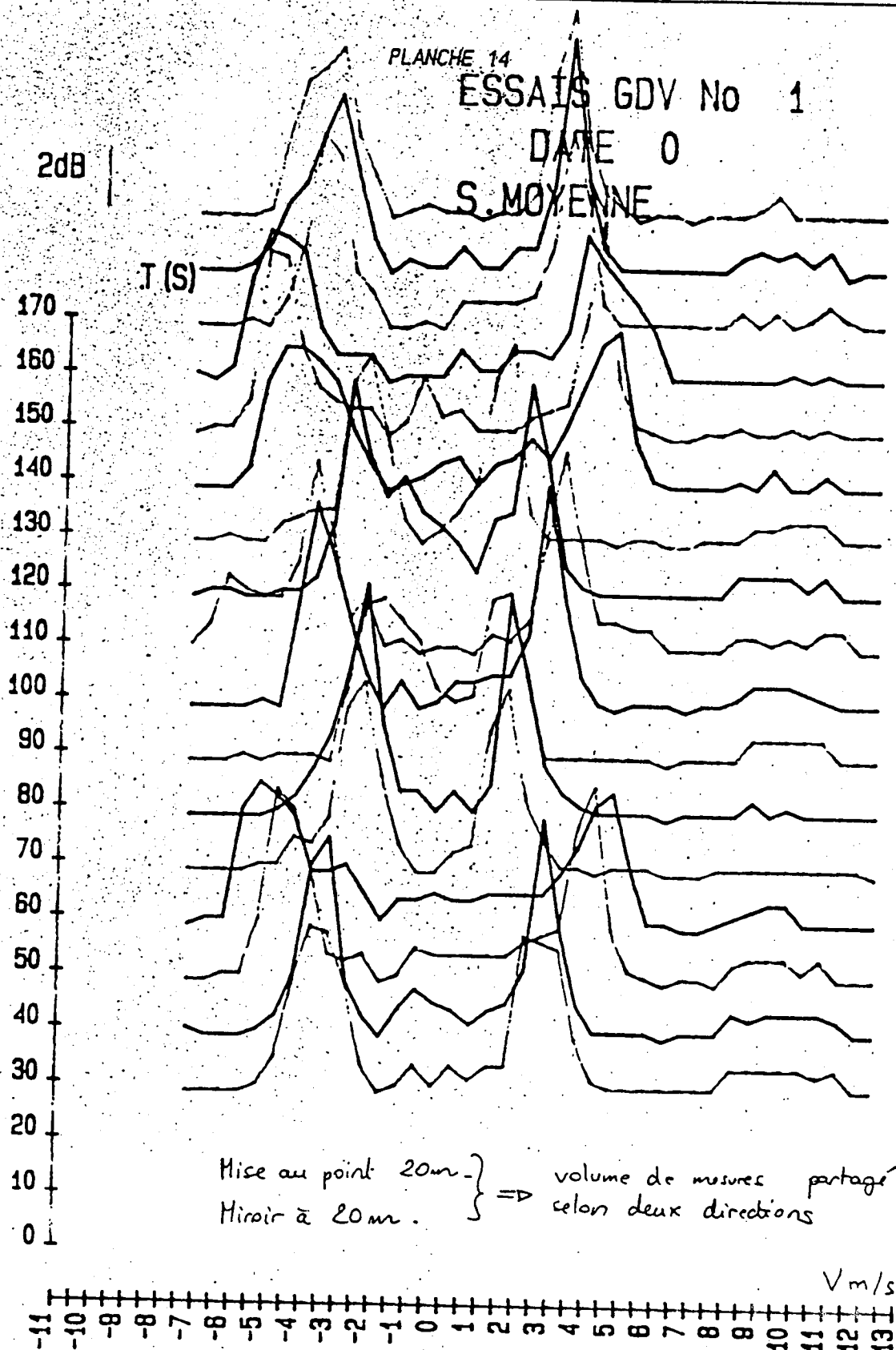
ESSAI SUR VALENCE : variation continue de 10m à 200m

PLANCHE 12

.(GDV)   RAPPORT S/N

S/N (dB)

passage d'hélicoptère
T (s)

PLANCHE 18

passage hélicoptère à t = 0 s

Retour au calme à t = 160 s
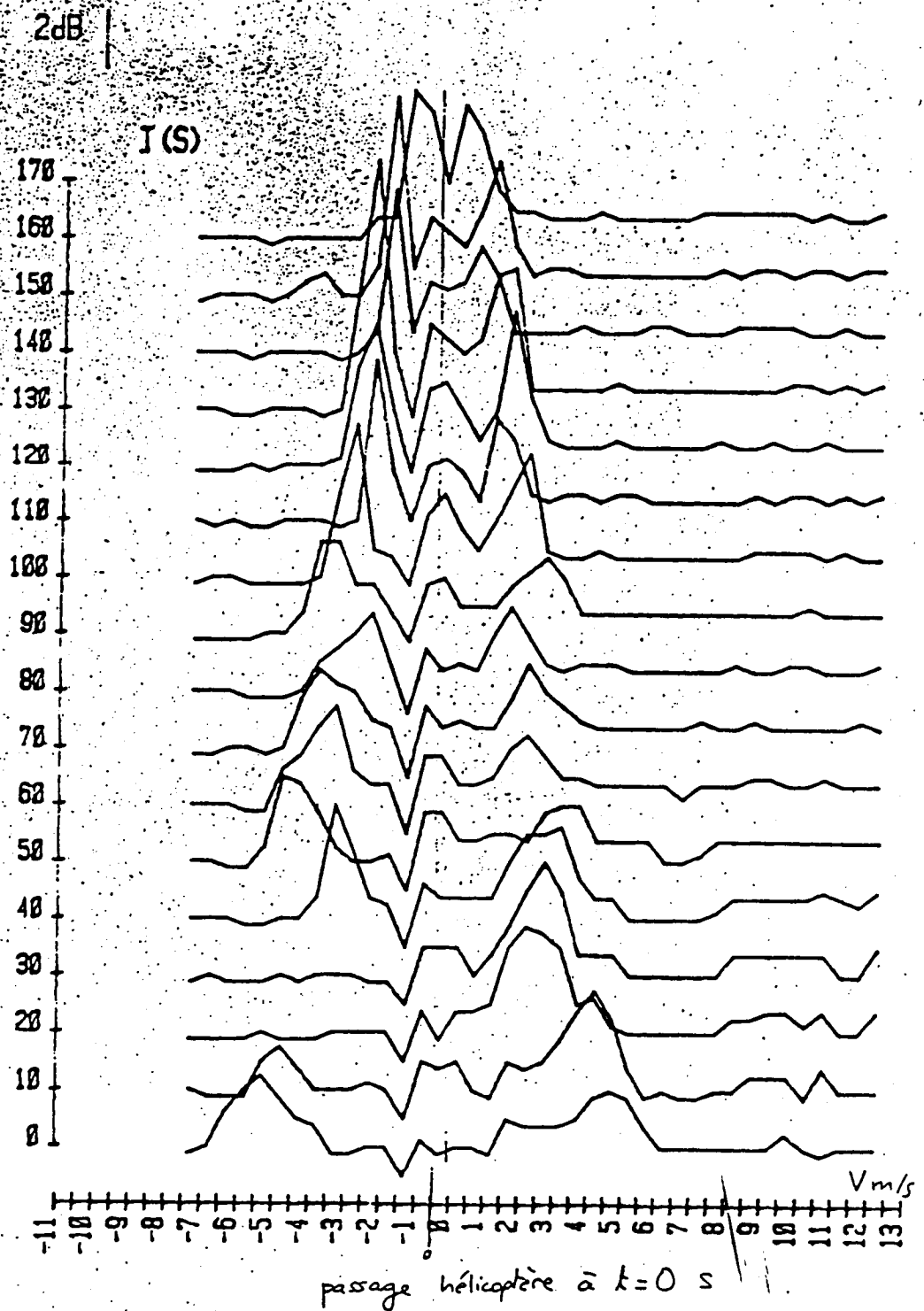
PLANCHE 24

(GDV). VITESSE AIR

y (m/s)
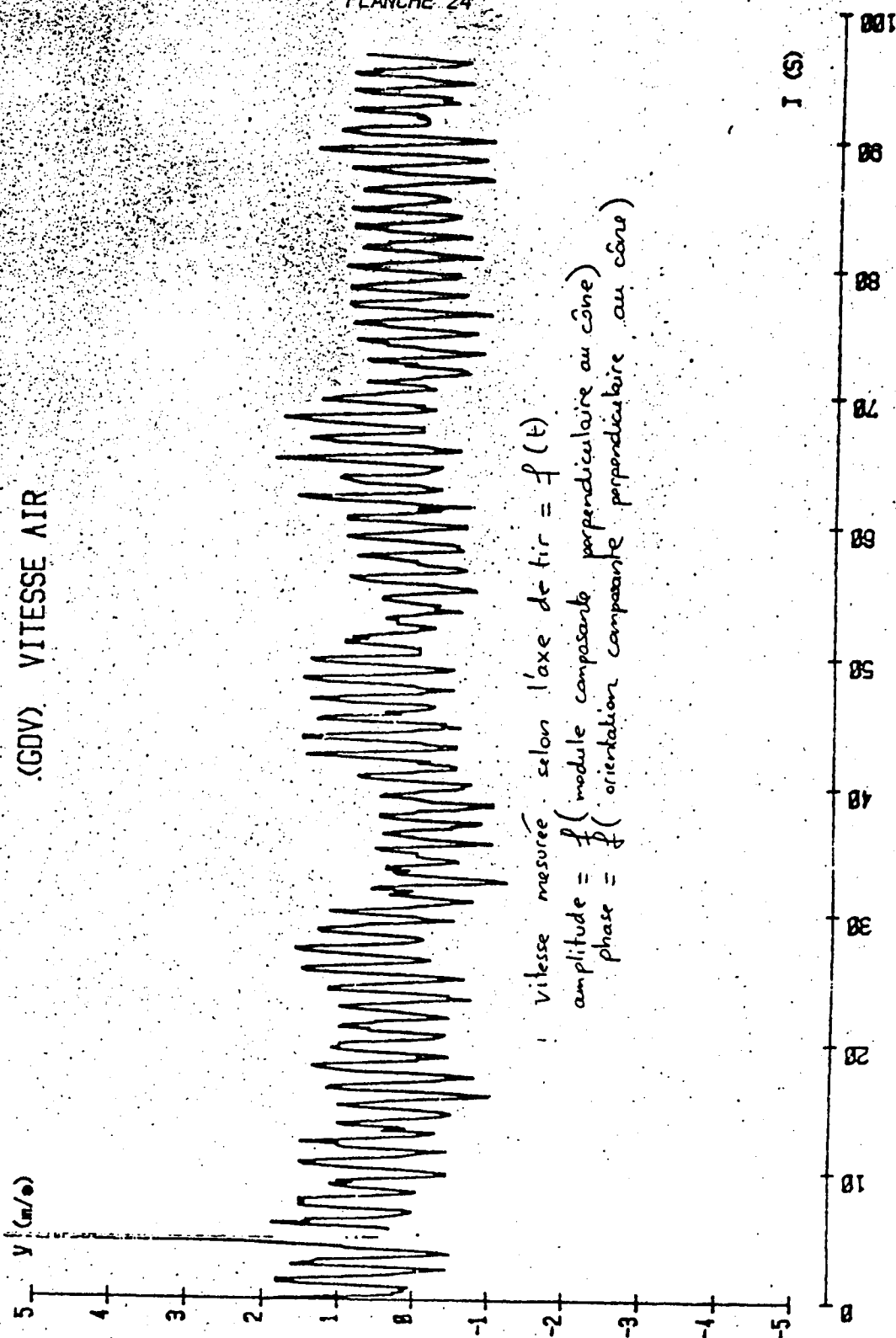
vitesse mesurée selon l'axe de tir = $f(t)$

amplitude = f (module composante perpendiculaire au cône)

phase = f (orientation composante perpendiculaire au cône)

T (S)

Crouzet

PLANCHE 25

(GDV) VITESSE AIR

"accidents" de la sinusoïde dûs aux inhomogénéités du champ de vent.

SPECTRE MOYENNE N# 65

ESSAI N# 57   DATE : 32/1984

PLANCHE 34

14.75 dB

12.15

9.55

6.95

4.35

1.75

75.1   42.2   9.6   M/S

vol stationnaire à 50m par temps de pluie

distance de mesure : 100m

dédoublement de spectre dû à la différence de vitesse entre air et pluie.

(8,2 et 6,3 m/s)

617
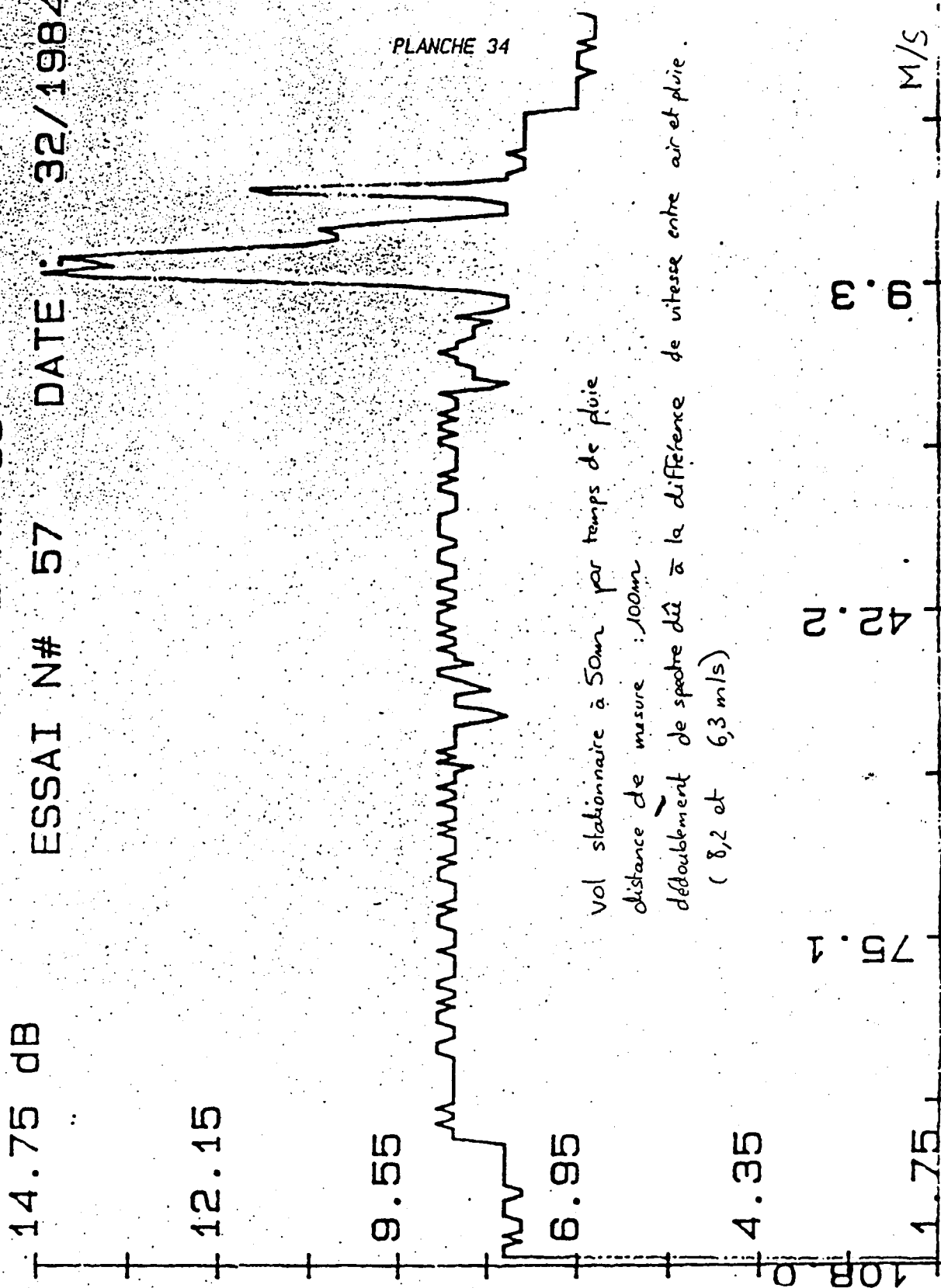
PLANCHE 35

DATE 291087
S. MOYENNE

2dB

T (S)
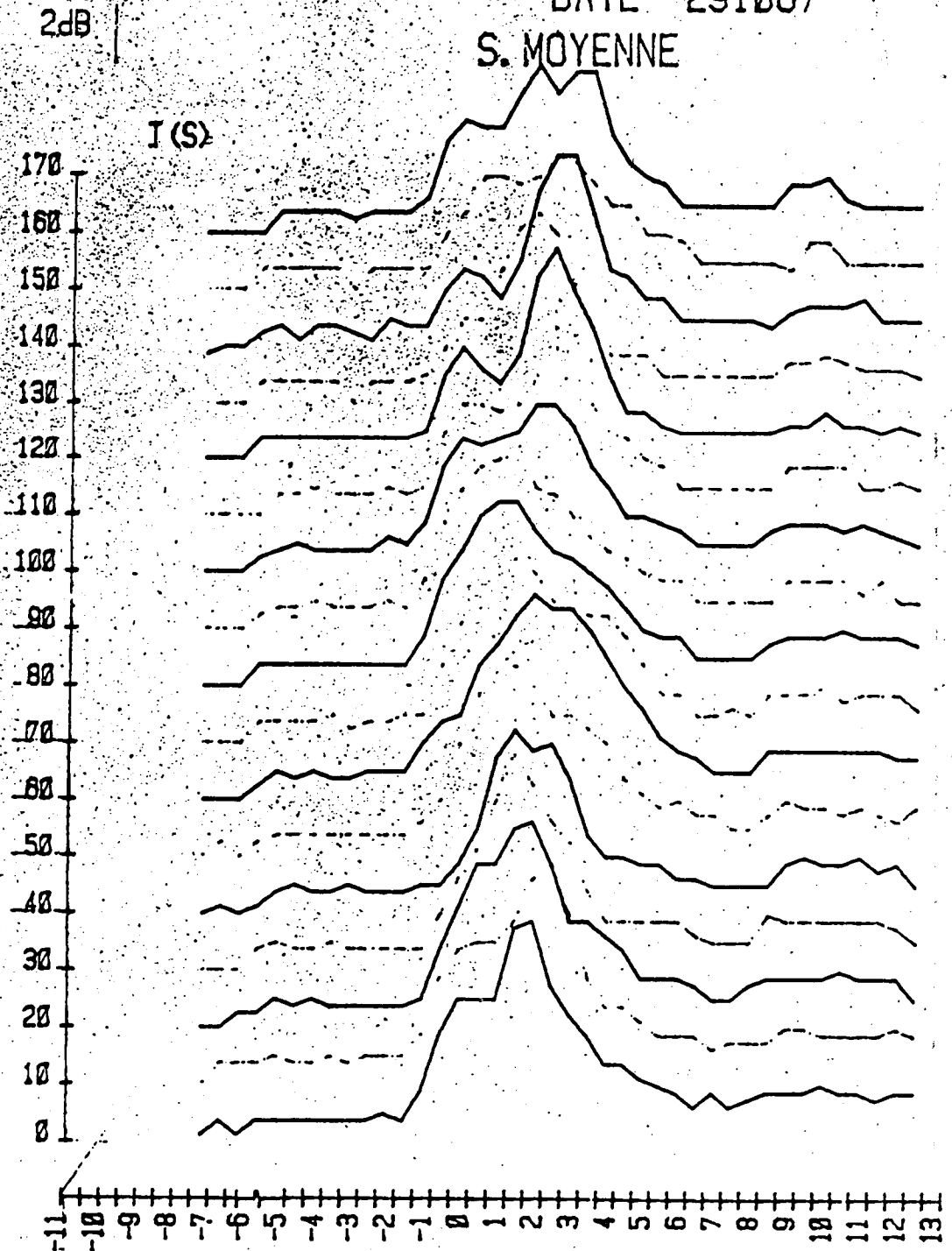
Mesure à 100m par vent léger fluctuant avec pluie moyenne -
Spectres élargis par vitesses variables pluie et turbulences . 618
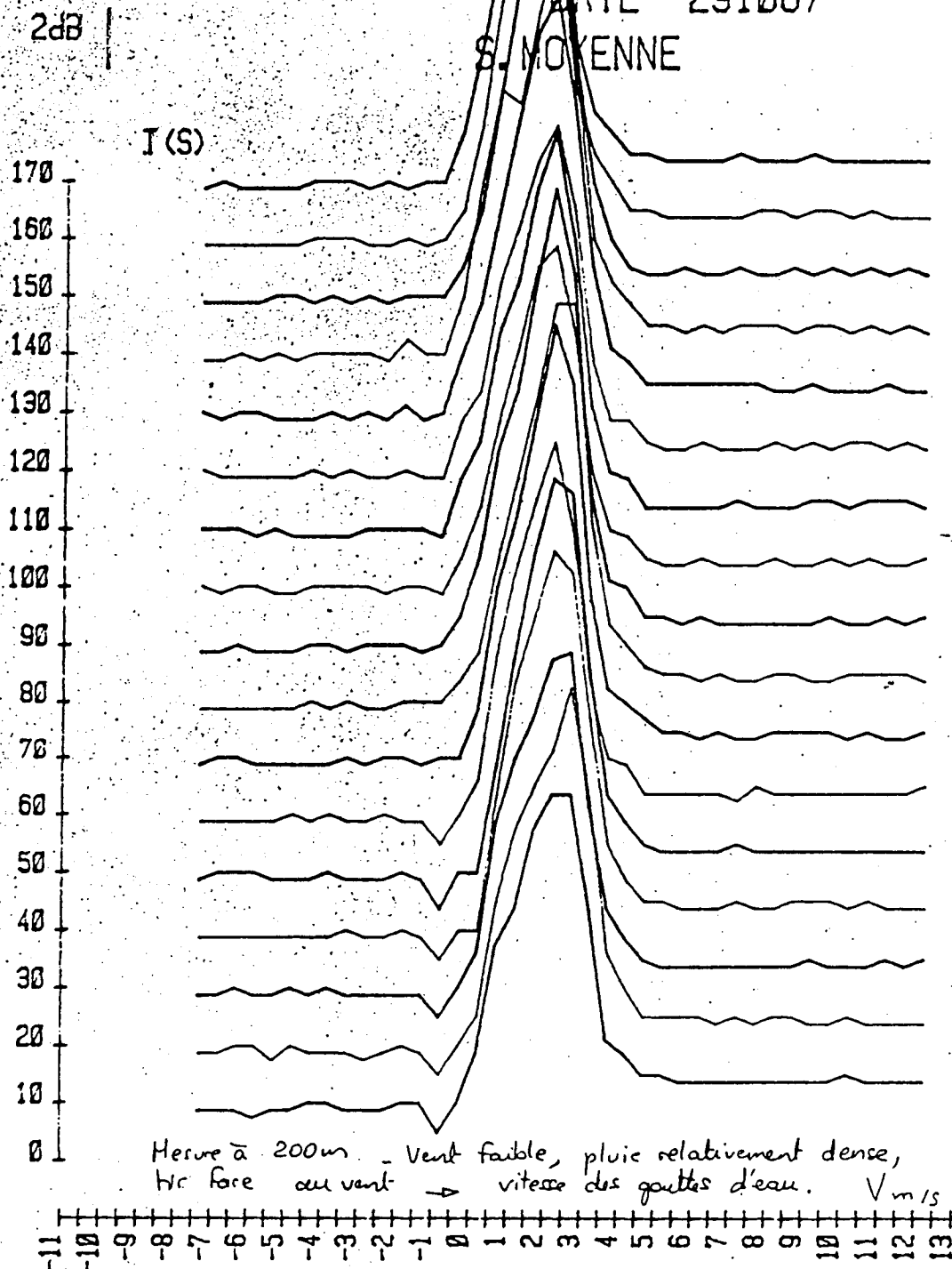
V (m/s)

PLANCHE 36

ESSAIS
DATE 291087
S. MOYENNE

2dB

T(S)

Heure à 200m _ Vent faible, pluie relativement dense,
tir face au vent ⟶ vitesse des gouttes d'eau. V m/s

Crouzet

619

PLANCHE 36

ESSAIS
DATE 291087
S. MOYENNE

2dB

I(S)

Heure à 200m — Vent faible, pluie relativement dense,
Hr face au vent → vitesse des gouttes d'eau. Vm/s
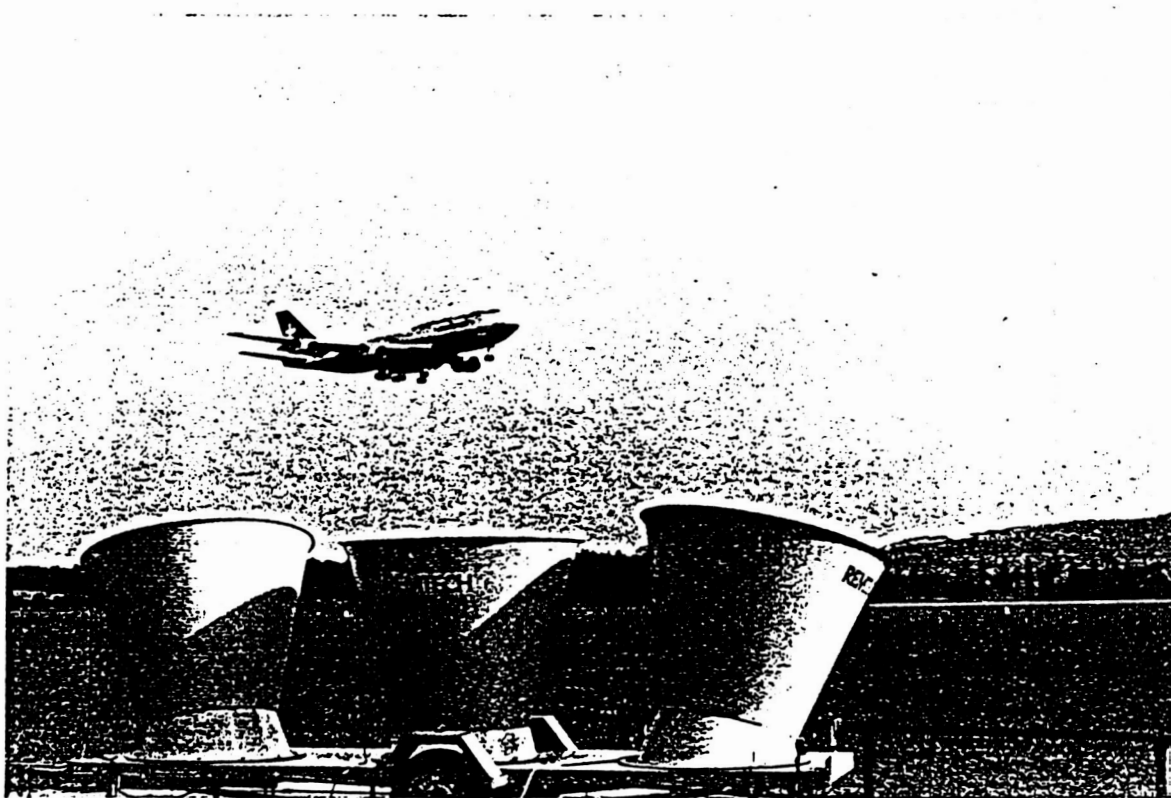
SODAR antennae at Zürich Airport
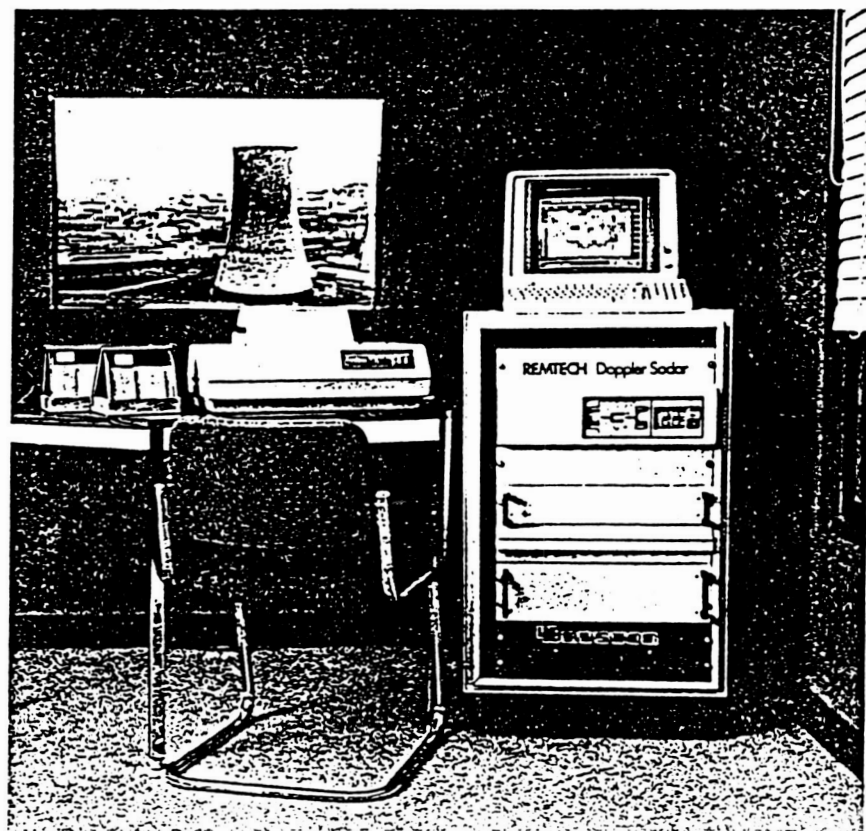
SODAR electronic cabinet

620

| 1 | 6 | 10 | 36 | 11 | 15 | 1 | 0 | 0 | 255 | | |

RANGE	ECHU	S ECHO	SPEED	TETA	S TETA	W	S W	ETAM	STA	S U	S V
CTS		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
440	-9999	-9999									
420	-9999	-9999									
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	-9999	-9999									
280	-9999	-9999									
260	-9999	-9999									
240	-9999	-9999									
220	-9999	-9999									
200	-9999	-9999									
180	-9999	-9999									
160	140	59	-9999	-9999	-9999	-112	163	0	0	0	0
140	145	42	-9999	-9999	-9999	-144	163	0	0	0	0
120	190	55	-9999	-9999	-9999	-144	145	0	0	0	0
100	245	56	-9999	-9999	-9999	-142	134	0	0	0	0
80	249	40	-9999	-9999	-9999	-127	135	0	0	0	0
60	269	23	-9999	-9999	-9999	-157	145	0	0	0	0
10	0	0	0	-9999	-9999	-164	163	0	0	0	0
2	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0			

| M | 6 | 10 | 36 | 11 | 29 | 58 | 0 | 0 | 481 | | |

RANGE	ECHO	S ECHO	SPEED	TETA	S TETH	W	S W	ETAM	STA	S U	S V
CTS		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
440	-9999	-9999									
420	-9999	-9999									
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	-9999	-9999									
280	-9999	-9999									
260	-9999	-9999									
240	-9999	-9999									
220	84	51	-9999	-9999	-9999	-226	120	0	0	0	0
200	103	39	-9999	-9999	-9999	-181	147	0	0	0	0
180	100	40	-9999	-9999	-9999	-242	145	0	0	0	0
160	102	51	-9999	-9999	-9999	-189	138	0	0	0	0
140	113	52	-9999	-9999	-9999	-157	138	0	0	0	0
120	134	49	-9999	-9999	-9999	-177	131	0	0	0	0
100	166	60	-9999	-9999	-9999	-177	128	0	0	0	0
80	185	51	-9999	-9999	-9999	-168	124	0	0	0	0
60	231	43	-9999	-9999	-9999	-144	109	0	0	0	0
10	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0			

621

DM   7   3   37   12   50   0   0   0   572

RANGE	ECHO	S ECHO	SPEED	TETA	S TETA	W	S W	ETAM	STA	S U	S V
CTS		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	132	53	-9999	-9999	-9999	363	49	0	0	0	0
280	-9999	-9999									
260	178	40	-9999	-9999	-9999	375	65	0	0	0	0
240	188	53	-9999	-9999	-9999	325	103	0	0	0	0
220	203	51	-9999	-9999	-9999	321	121	0	0	0	0
200	232	50	-9999	-9999	-9999	334	115	0	0	0	0
180	233	64	-9999	-9999	-9999	333	90	0	0	0	0
160	284	58	-9999	-9999	-9999	316	75	0	0	0	0
140	349	52	-9999	-9999	-9999	317	67	0	0	0	0
120	411	46	-9999	-9999	-9999	323	74	0	0	0	0
100	401	33	-9999	-9999	-9999	317	93	0	0	0	0
80	368	32	-9999	-9999	-9999	265	105	0	0	0	0
60	339	20	-9999	-9999	-9999	235	140	0	0	0	0
10	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0			

DM   7   3   87   12   59   59   0   0   639

	RANGE	ECHO	S ECHO	SPEED	TETA	S TETA	W	S W	ETAM	STA	S U	S V
S	CTS		0.000									
S	INV	0	0	0	0	0	0	0	0	0	0	0
I	400	-9999	-9999									
I	380	-9999	-9999									
I	360	-9999	-9999									
I	340	-9999	-9999									
I	320	-9999	-9999									
V	300	143	30	-9999	-9999	-9999	242	93	0	0	0	0
V	280	123	47	-9999	-9999	-9999	270	75	0	0	0	0
I	260	-9999	-9999									
V	240	166	82	-9999	-9999	-9999	179	75	0	0	0	0
V	220	205	68	-9999	-9999	-9999	204	82	0	0	0	0
V	200	132	62	-9999	-9999	-9999	175	91	0	0	0	0
V	180	252	69	-9999	-9999	-9999	178	95	0	0	0	0
V	160	302	76	-9999	-9999	-9999	168	92	0	0	0	0
V	140	316	62	-9999	-9999	-9999	174	88	0	0	0	0
V	120	393	38	-9999	-9999	-9999	176	89	0	0	0	0
V	100	428	33	-9999	-9999	-9999	148	100	0	0	0	0
V	80	416	25	-9999	-9999	-9999	142	106	0	0	0	0
V	60	369	16	-9999	-9999	-9999	133	94	0	0	0	0
A	10	0	0	0	90	0	0	0	0	0	0	0
A	2	0	0	0	0	0	0	0	0	0	0	0
A	2	0	0	0	0	0	0	0	0	0	0	0
A	2	0	0	0	0	0	0	0	0			
S												

Figure 1

PARAISONS SODAR/ANEMOMETRES 31-MARS-88 ANEM.1 ET 2:PISTES 09/27 ET 10/28

623

Figure 2

COMPARAISONS SODAR/ANEMOMETRES 01-AVRIL-88 ANEM.1 ET 2:PISTES 09/27 ET 10/28
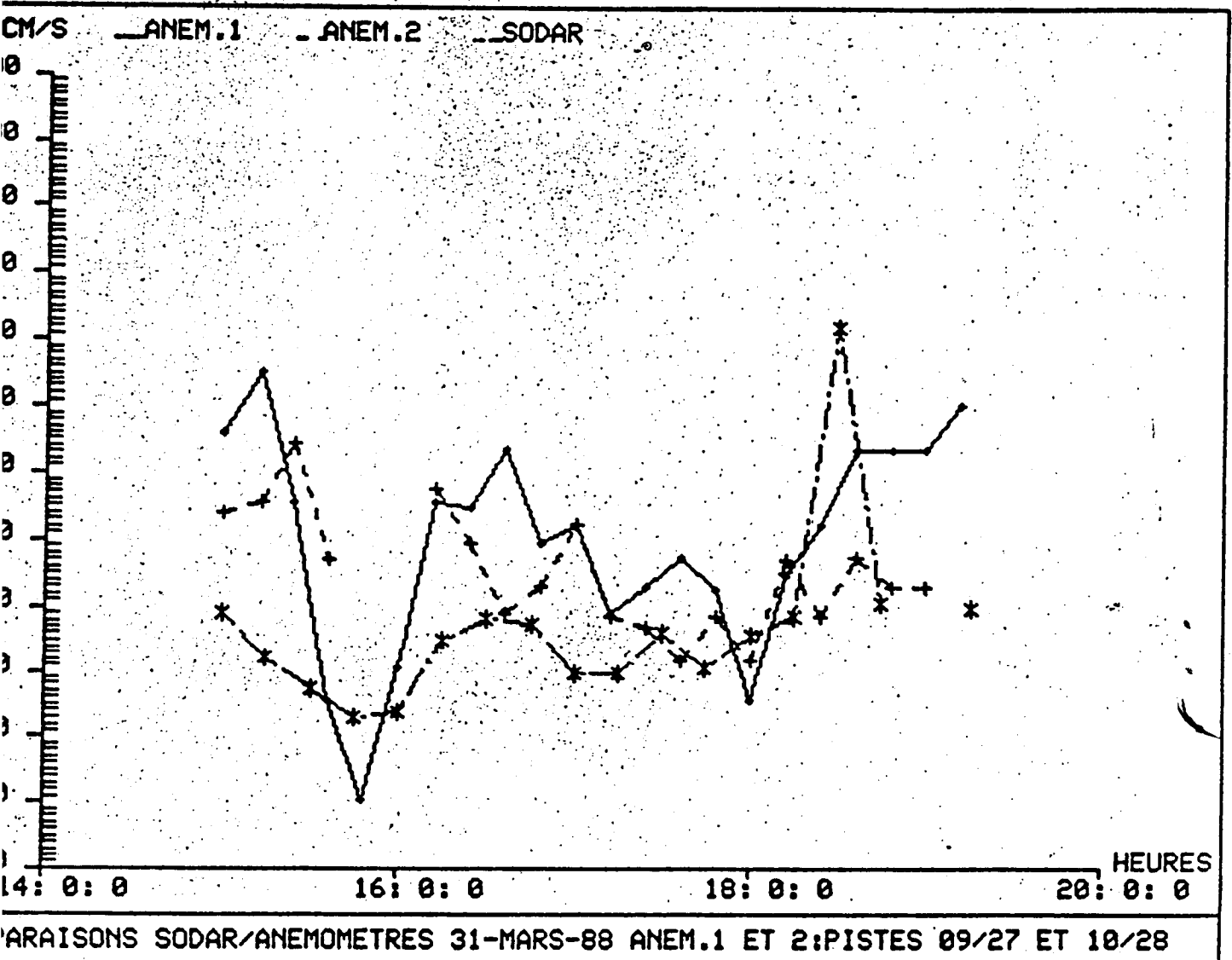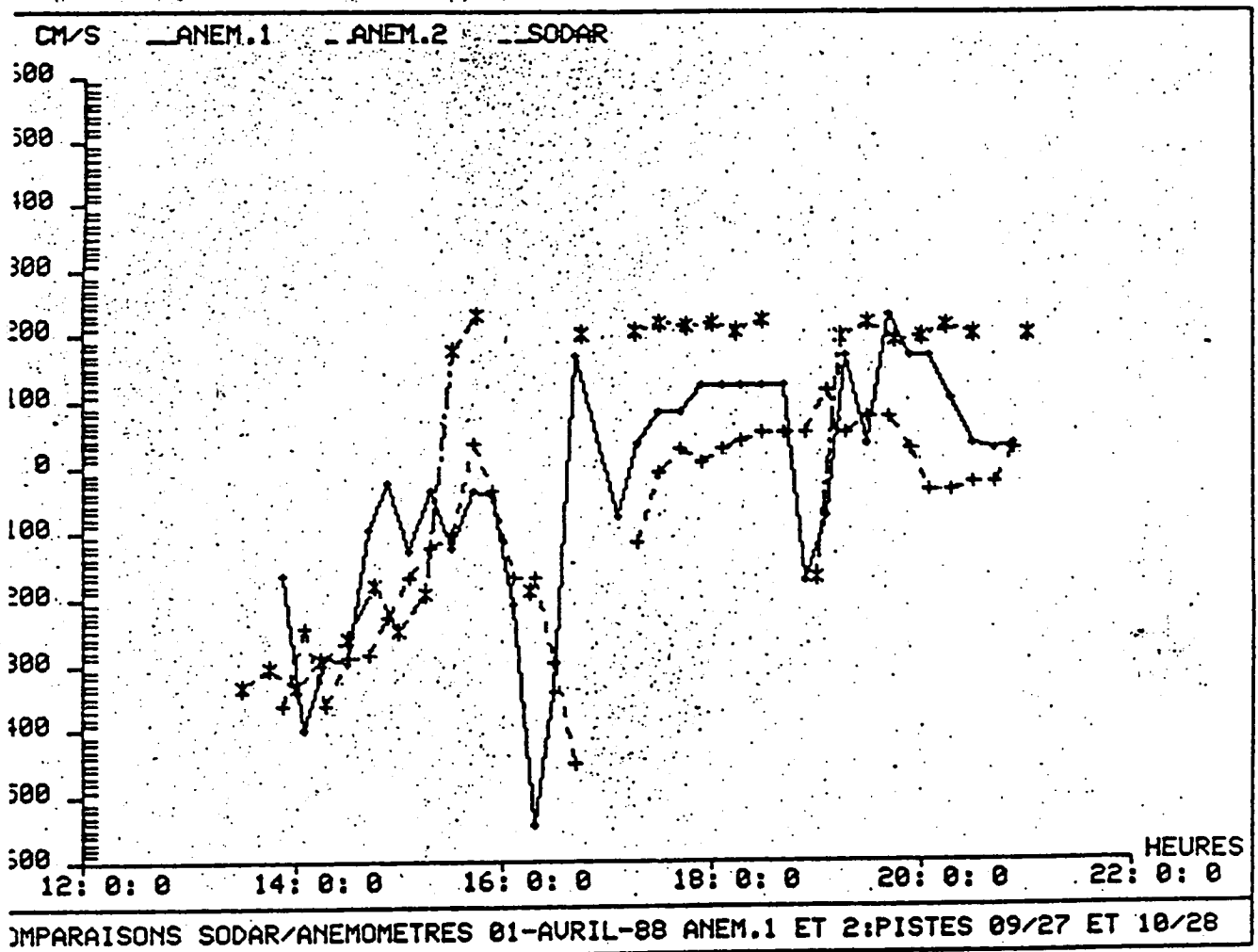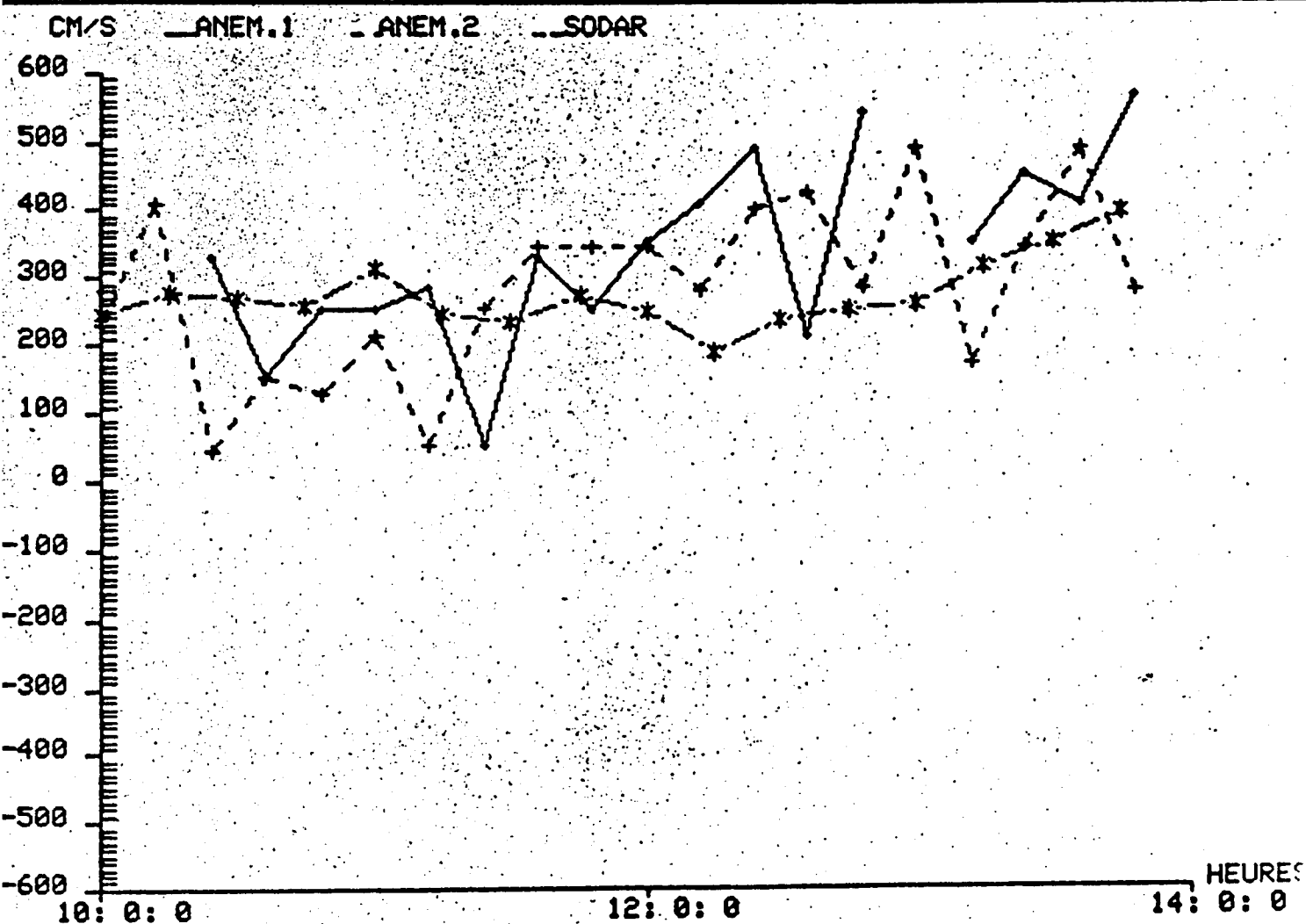
Figure 3

COMPARAISONS SODAR/ANEMOMETRES 02-AVRIL-88 ANEM.1 ET 2:PISTES 09/27 ET 10/28
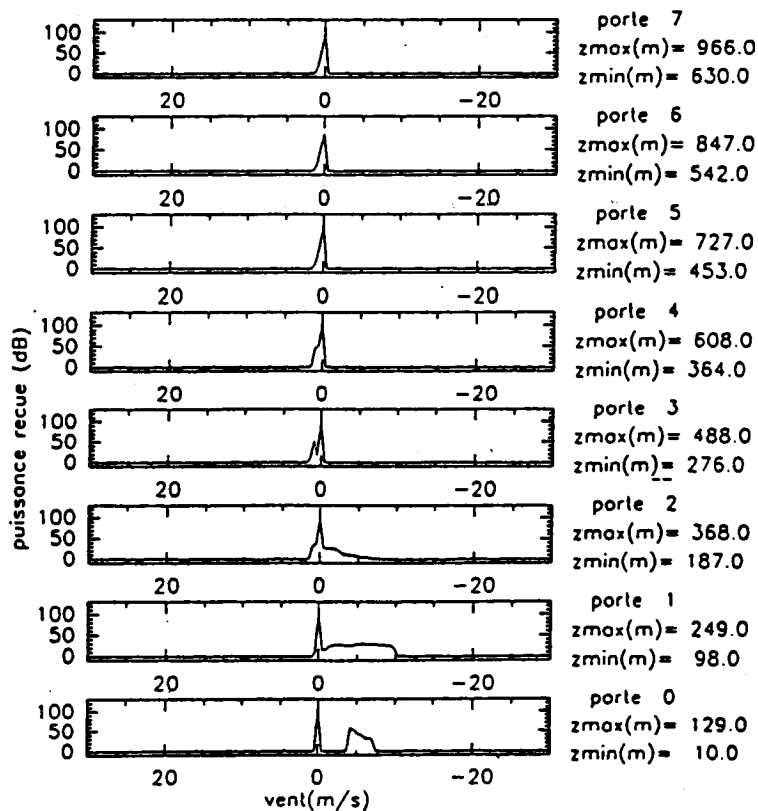
Figure 4
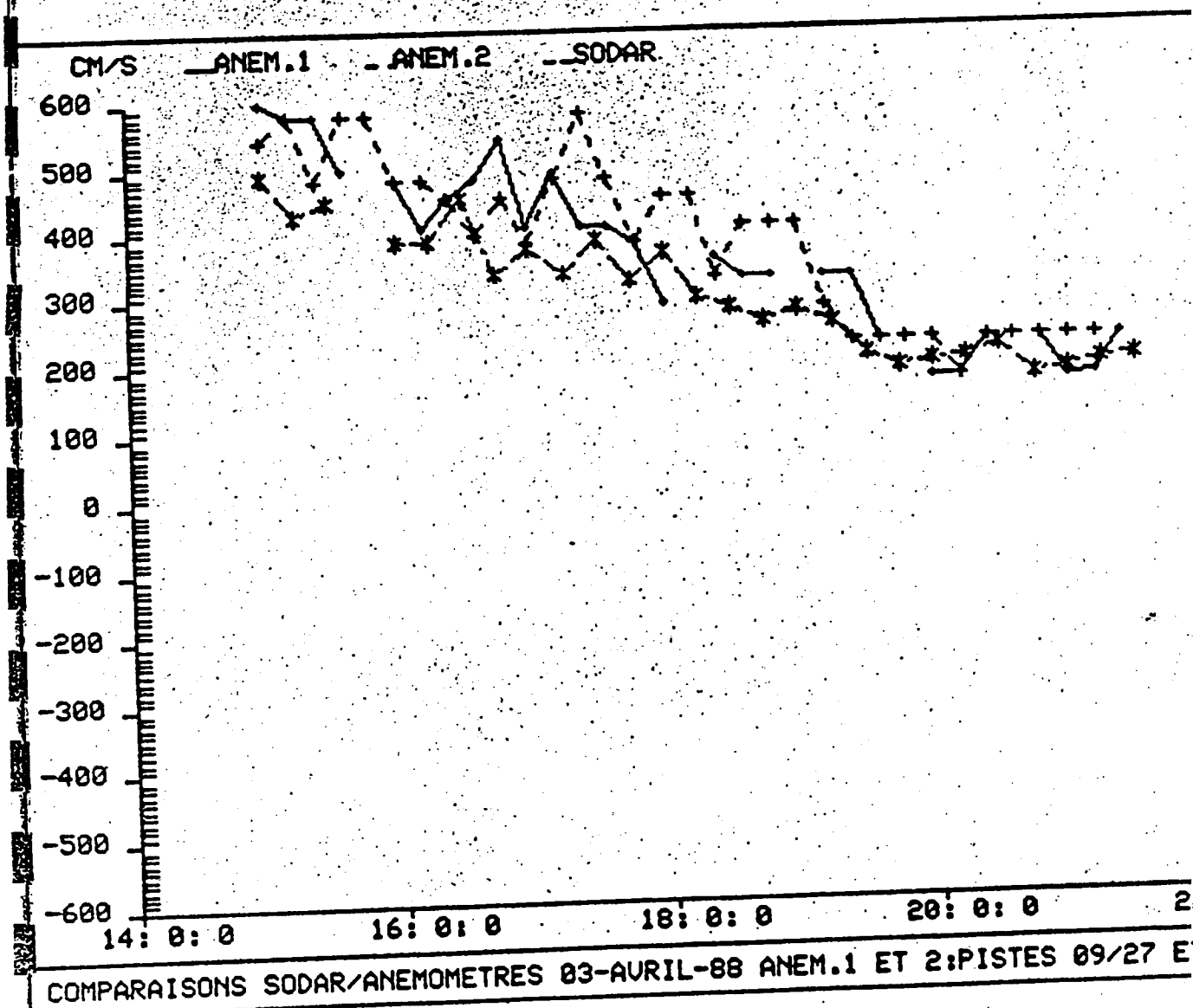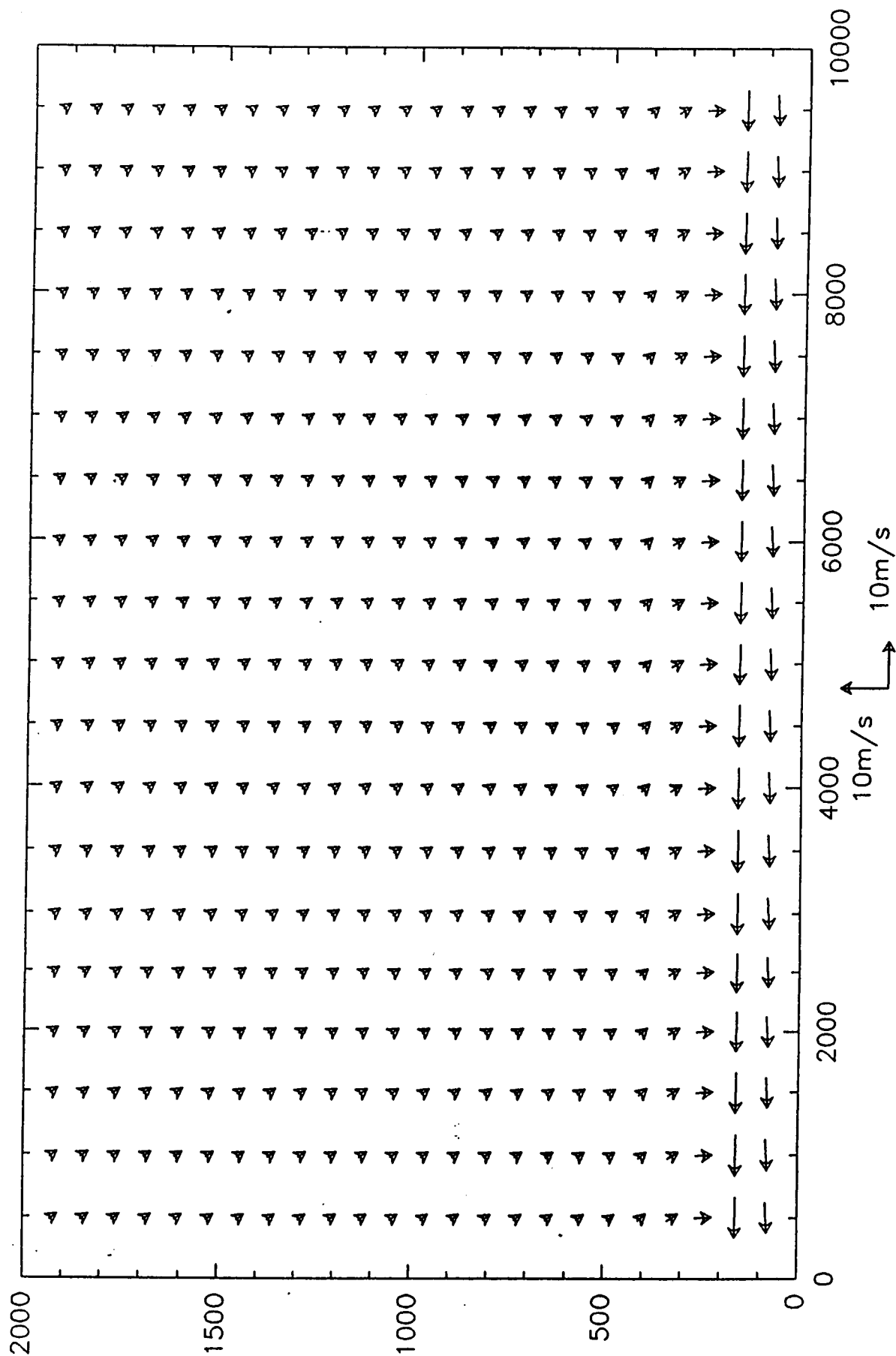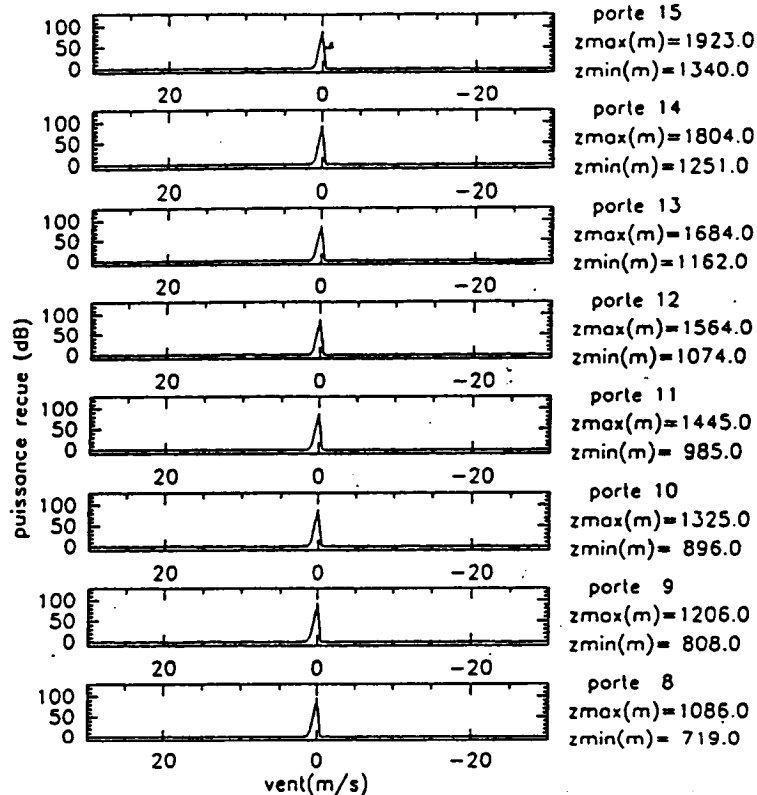
CM/S   _ANEM.1   _ ANEM.2   _ SODAR

COMPARAISONS SODAR/ANEMOMETRES 03-AVRIL-88 ANEM.1 ET 2:PISTES 09/27 ET

modele 6   decollage

10m/s

10m/s

porte 15
zmax(m)=1923.0
zmin(m)=1340.0

porte 14
zmax(m)=1804.0
zmin(m)=1251.0

porte 13
zmax(m)=1684.0
zmin(m)=1162.0

porte 12
zmax(m)=1564.0
zmin(m)=1074.0

porte 11
zmax(m)=1445.0
zmin(m)= 985.0

porte 10
zmax(m)=1325.0
zmin(m)= 896.0

porte 9
zmax(m)=1206.0
zmin(m)= 808.0

porte 8
zmax(m)=1086.0
zmin(m)= 719.0

altitude du radar(m)	=	10.0
puissance crete(W)	=	4500.
larg-impulsion(micro-s)	=	4.00
longueur d'onde(cm)	=	30.00
angle de visee(deg)	=	80.00
ouverture-antenne(deg)	=	1.50
gain de l'antenne(dB)	=	41.7
niveau-lobes-second.(dB)	=	20.0

$Z_e = 0\,dB_z$

porte 7
zmax(m)= 966.0
zmin(m)= 630.0

porte 6
zmax(m)= 847.0
zmin(m)= 542.0

porte 5
zmax(m)= 727.0
zmin(m)= 453.0

porte 4
zmax(m)= 608.0
zmin(m)= 364.0

porte 3
zmax(m)= 488.0
zmin(m)= 276.0

porte 2
zmax(m)= 368.0
zmin(m)= 187.0

porte 1
zmax(m)= 249.0
zmin(m)= 98.0

porte 0
zmax(m)= 129.0
zmin(m)= 10.0

modele 6

decollage

donc une éventuelle variation des valeurs extrêmes du vent observé.
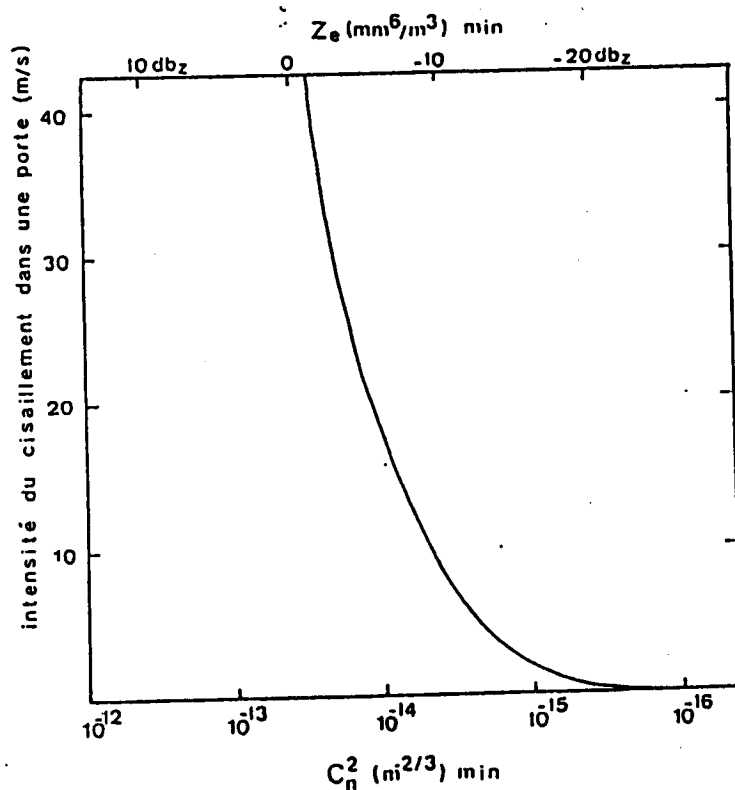
Figure (1,4) Réflectivité minimum (exprimée en C_n^2) requise à une distance $r = 10km$ pour assurer une bonne détectabilité d'un cisaillement de vent d'amplitude donnée enordonnée.On retrouve, pour un cisaillement de vent nul, la valeur théorique calculée au § (I.1.3.a).

cisaillement de vent en présence d'échos de sol sont fournis en Annexe V. Les principaux résultats de cette simulation en ce qui concerne les échos de sol sont résumés dans les figures (2,7) et (2,8) ci après.

$$P_c / P_b \ (dB)$$
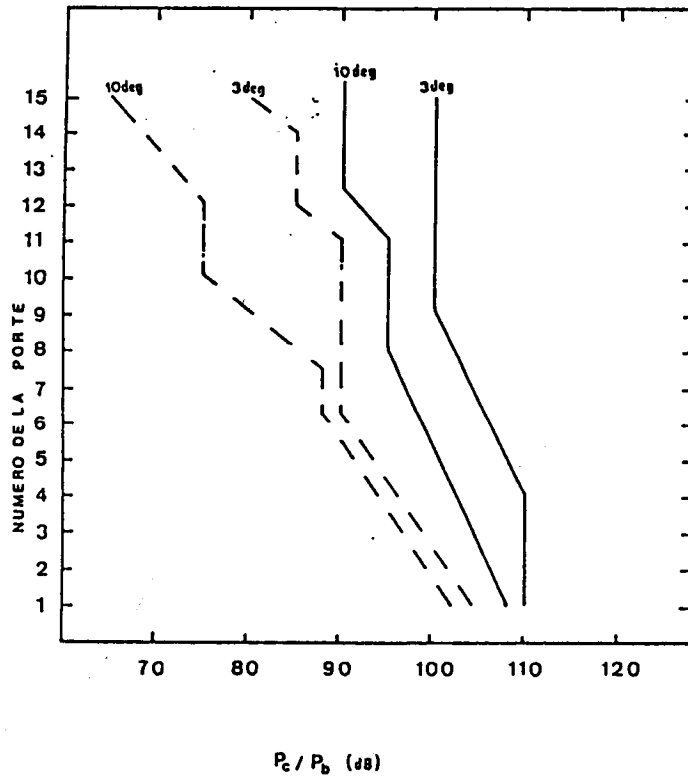
Figure (2,7): variation du rapport puissance clutter/ puissance bruit
par filtre équivalent FFT, en fonction de la distance (portes 1 à 15);
pour deux valeurs de l'angle de visée ($\alpha = 3deg$ et $\alpha = 10$ deg);
et pour deux valeurs différentes du niveau des lobes secondaires de
l'antenne:
    20 dB en traits pleins
    30 dB en tiretés
L'ouverture de l'antenne est ici de $\Theta = 4$ deg

Dans cette simulation, on a fait varier l'ouverture de l'antenne (Θ) ; l'angle de visée (α) ; et le niveau des lobes secondaires. Le tableau ci-dessous donne l'ensemble des variations utilisées :

Θ	Niveau lobes secondaires	angles de visée
3°	-20 dB ; -30 dB	3° et 10°
4°	-20 dB ; -30 dB	3° et 10°
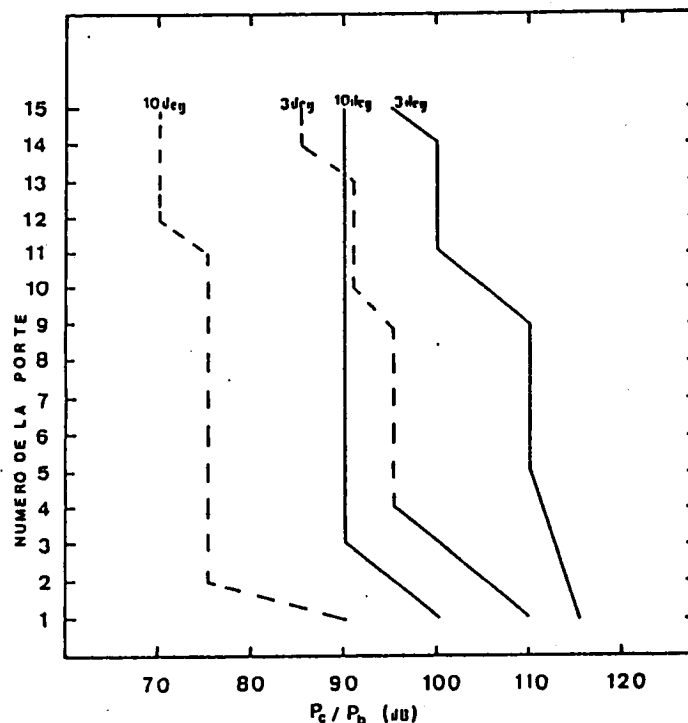
Figure (2,8) : même chose que sur la fig.(2,7) mais avec une antenne d'ouverture Θ = 3 deg.

L'analyse de cette simulation appelle plusieurs remarques.

1°) Le rapport Puissance de l'écho/Puissance du Bruit (P_C/P_B) varie en fonction de la distance pour chaque ouverture d'antenne et angle de visée. Les figures (2.7) et (2.8) résument les variations obtenues dans chaque porte radar (15 portes de 600m) en fonction de l'angle de visée pour des niveaux de lobes secondaires de -20 et -30 dB et pour deux valeurs d'ouverture d'antenne : Θ = 4° (fig. 2.7) et Θ = 3° (fig. 2.8).

Pour Θ = 4° le rapport P_C/P_B est peu sensible (dans les premières portes) aux variations de l'angle de visée et au niveau des lobes secondaires. Il reste à un niveau de

ALTI   S/B (dB)
(m)

VENT (m/s)
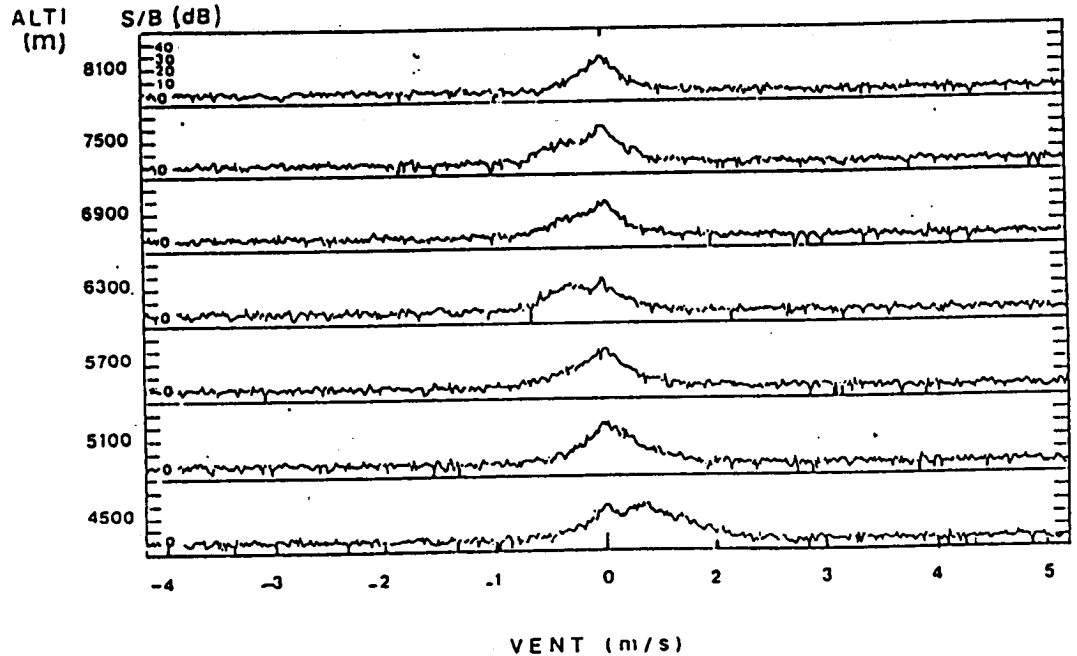
*Figure (2,9) : Spectres bruts obtenus à Saint Santin par le radar
PROUST visant à la verticale (rapport Signal/Bruit en fonction de
la fréquence exprimée en terme de vent vertical) pour les portes
4 à 10 (4500m à 8100m d'altitude). La situation météorologique est
anticyclonique et le ciel sans nuages. Les échos de sol occupent le
centre du spectre (autour du Doppler nul) dans un domaine spectral
correspondant à +/- 0.6 m/s. On voit également apparaître un signal
"air clair" qui est dans certaines portes entièrement masqué par l'écho
de sol*
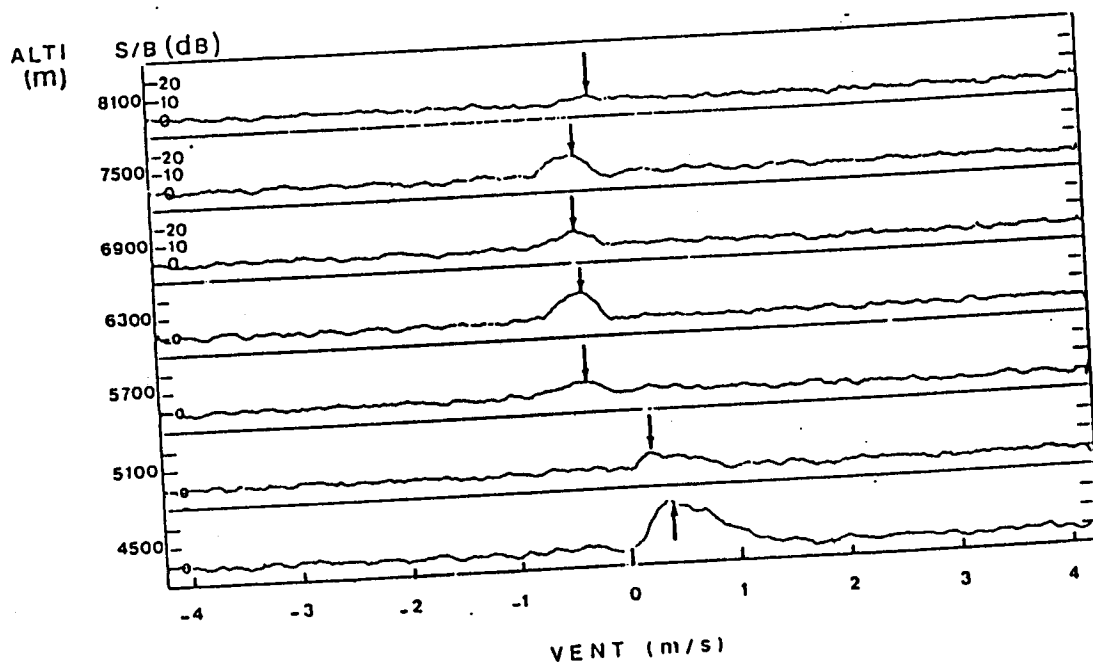
Figure (2,10) : Spectres atmosphériques "air clair" obtenus après élimination des échos de sol par la méthode d'ajustement décrite dans le § I.2.1.6.2.2°.

modele 14 atterrissage

10m/s

10m/s

634
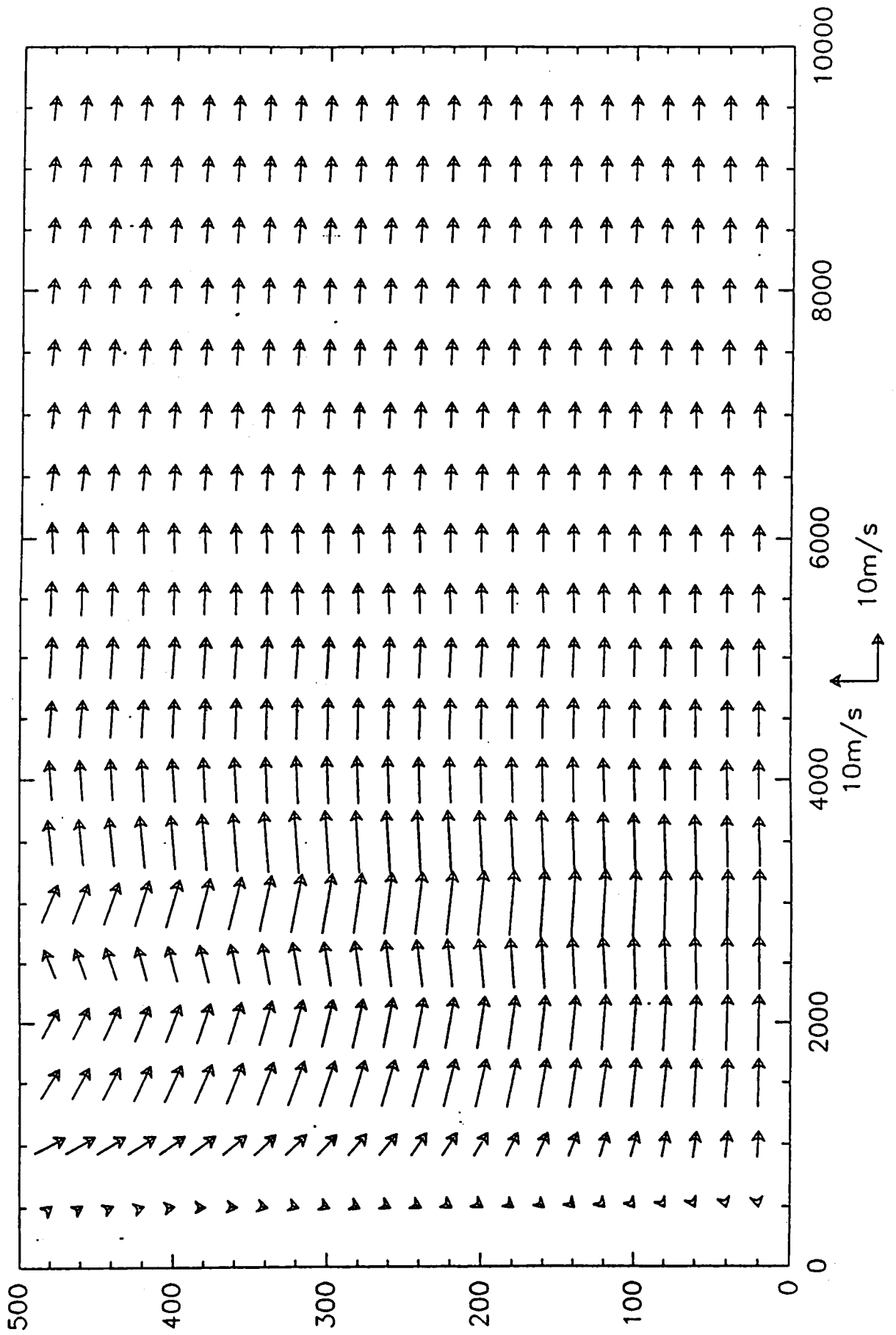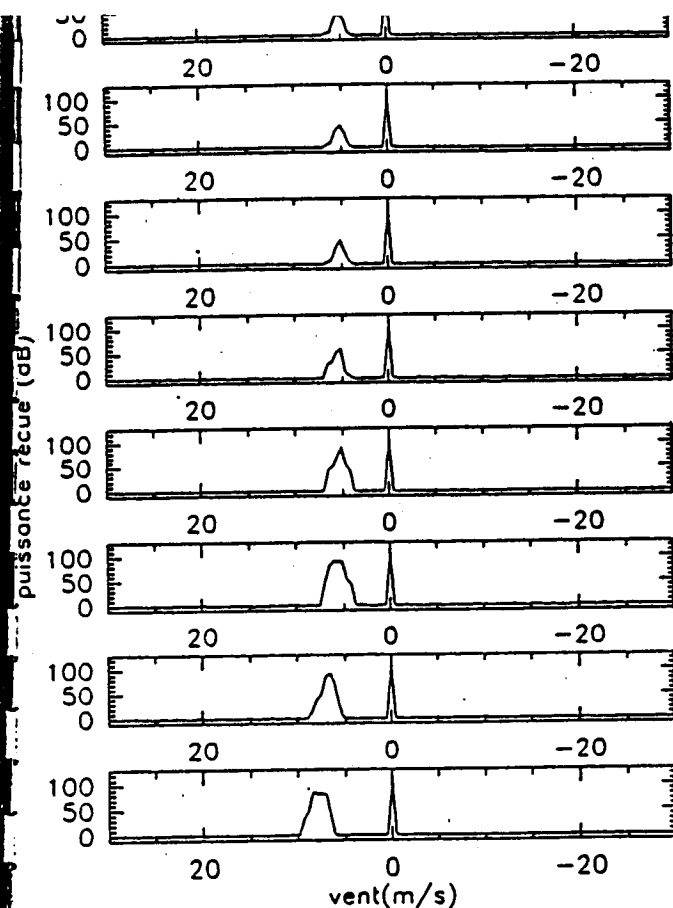
zmin(m)= 245.0

porte 14
zmax(m)= 715.0
zmin(m)= 229.0

porte 13
zmax(m)= 668.0
zmin(m)= 214.0

porte 12
zmax(m)= 621.0
zmin(m)= 198.0

porte 11
zmax(m)= 574.0
zmin(m)= 182.0

porte 10
zmax(m)= 527.0
zmin(m)= 166.0

porte 9
zmax(m)= 480.0
zmin(m)= 151.0

porte 8
zmax(m)= 433.0
zmin(m)= 135.0

puissance recue (dB)

vent(m/s)

altitude du radar(m)	=	10.0
puissance crete(W)	=	4500.
larg-impulsion(micro-s)	=	4.00
longueur d'onde(cm)	=	30.00
angle de visee(deg)	=	87.00
ouverture-antenne(deg)	=	1.50
gain de l'antenne(dB)	=	41.7
niveau-lobes-second.(dB)	=	20.0
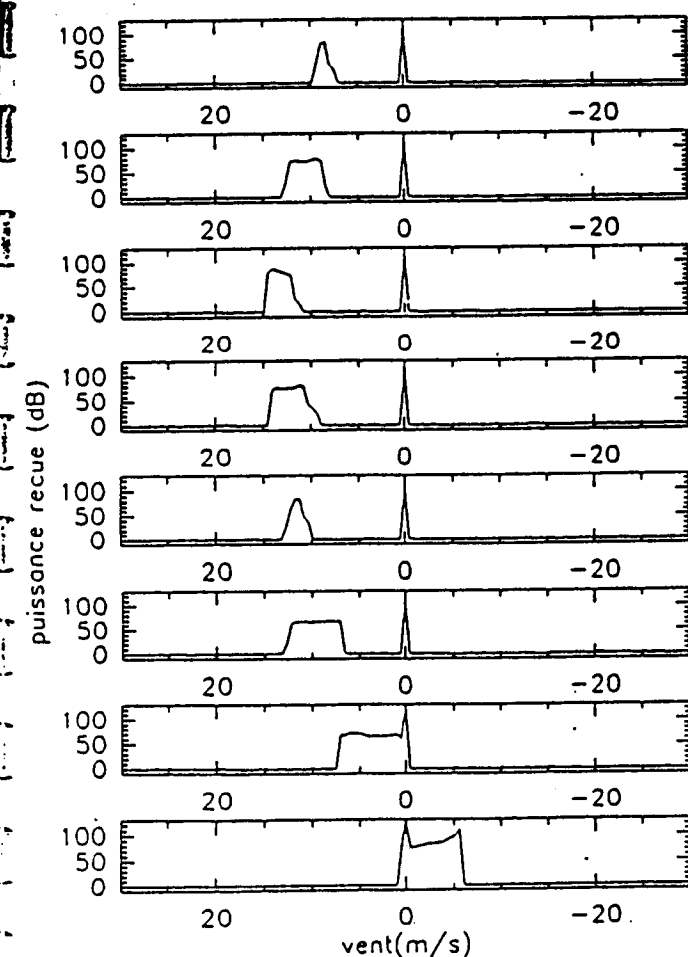
porte 7
zmax(m)= 386.0
zmin(m)= 119.0

porte 6
zmax(m)= 339.0
zmin(m)= 104.0

porte 5
zmax(m)= 292.0
zmin(m)= 88.0

porte 4
zmax(m)= 245.0
zmin(m)= 72.0

porte 3
zmax(m)= 198.0
zmin(m)= 57.0

porte 2
zmax(m)= 151.0
zmin(m)= 41.0

porte 1
zmax(m)= 104.0
zmin(m)= 25.0

porte 0
zmax(m)= 57.0
zmin(m)= 10.0

modele 14

atterrissage
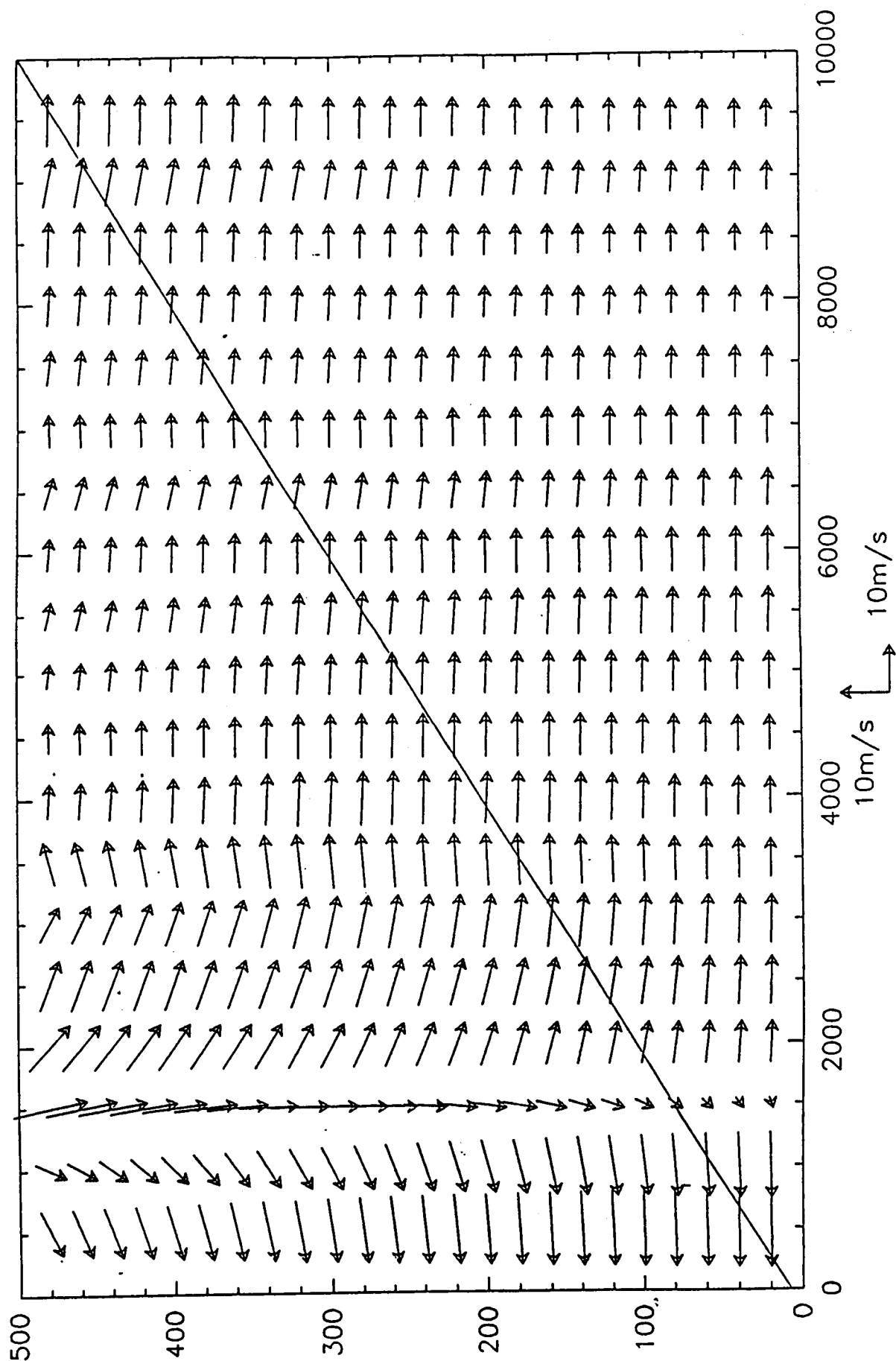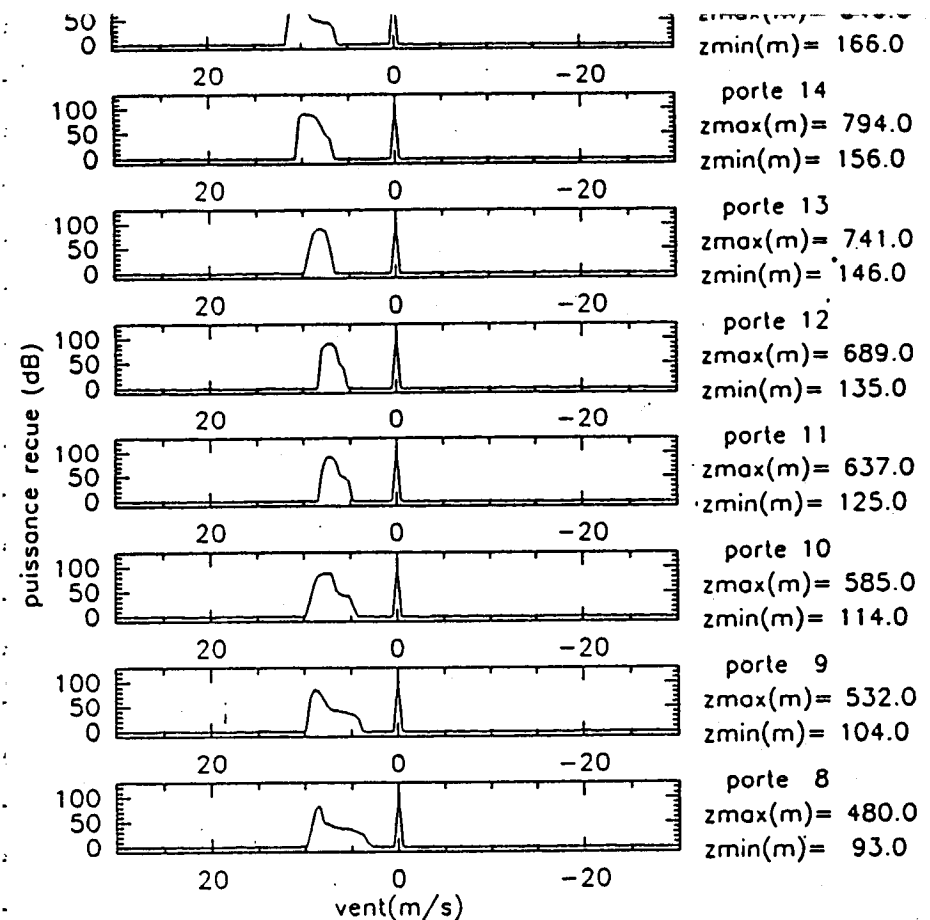
puissance recue (dB)

vent(m/s)

635

modele 8   atterrissage

636

porte 14
zmax(m)= 794.0
zmin(m)= 156.0

porte 13
zmax(m)= 7.41.0
zmin(m)= 146.0

porte 12
zmax(m)= 689.0
zmin(m)= 135.0

porte 11
zmax(m)= 637.0
zmin(m)= 125.0

porte 10
zmax(m)= 585.0
zmin(m)= 114.0

porte 9
zmax(m)= 532.0
zmin(m)= 104.0

porte 8
zmax(m)= 480.0
zmin(m)= 93.0

altitude du radar(m)   =   10.0
puissance crete(W)   =   4500.
larg-impulsion(micro-s)   =   4.00
longueur d'onde(cm) . .   =   30.00
angle de visee(deg)   =   87.00
ouverture-antenne(deg)   =.   2.00
gain de l'antenne(dB)   =   39.2
niveau-lobes-second.(dB) =   20.0
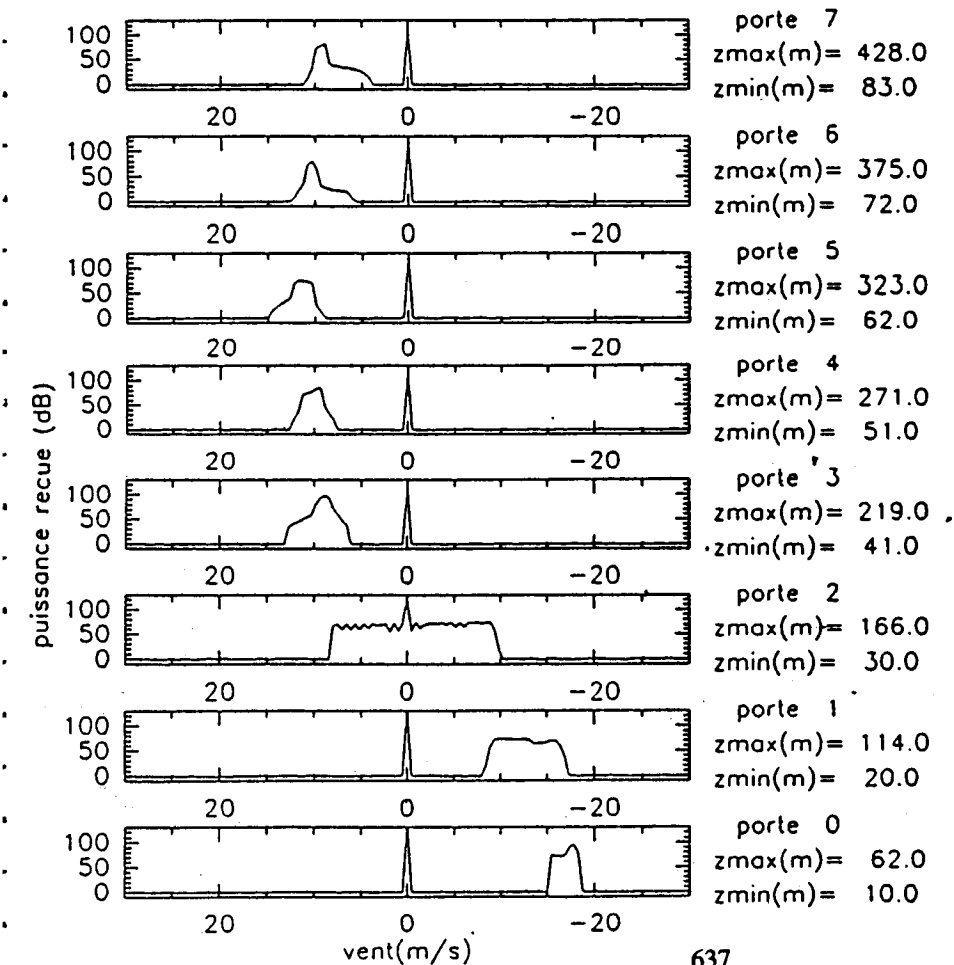
porte 7
zmax(m)= 428.0
zmin(m)= 83.0

porte 6
zmax(m)= 375.0
zmin(m)= 72.0

porte 5
zmax(m)= 323.0
zmin(m)= 62.0

porte 4
zmax(m)= 271.0
zmin(m)= 51.0

modele   8

atterrissage

porte 3
zmax(m)= 219.0 .
zmin(m)= 41.0

porte 2
zmax(m)= 166.0
zmin(m)= 30.0

porte 1
zmax(m)= 114.0
zmin(m)= 20.0

porte 0
zmax(m)= 62.0
zmin(m)= 10.0

637

(tape started in the middle of a sentence) with our three dimensional model, we are producing complex wind fields from different microburst events and 2) as the computers are growing more powerful, for example, a new computer, a Cray II will be delivered very soon at NASA. We will be able to run some very high resolution lines with those three dimensional models and as far as .. I mean, I say I wouldn't say that anybody working on these problems shouldn't use just model data by themselves, certainly they should try some of the observational data, but there's certain advantages with the model data in that we can provide very high resolution data of the wind fields and also we can provide other things like temperature, humidity, rain, snow, etc. Does that help?

For example, I mean the model cases that you sound so far are simulating microburst outflows. One possible source of nuisance alarms to this systems are strong divergences or velocity grading as seen on the backside of gust fronts and if those gust fronts aren't generated by the simulator, are you ever going to capture the nuisance alarms generated by those kinds of phenomena that will be perceived by the system? A: Well I think looking at a gust front, for example, if you run it through the F factor calculation and it exceeds, it either goes in a negative direction, which is not hazardous, or it doesn't last long enough, then it would be filtered out. I would like Roland to comment on gust front problems and we're trying to look at the microburst problems as the most severe and answer a question back, earlier you talked about using some real ground based data and we would like to do that if we can get the data that has this chaotic information in it, raw data, with resolutions in the order of 50 to 100 meters and I don't think that's available to get from anywhere so we've got to do it through simulation process.

Well, I guess there are different kinds of issues you can address and I'd argue that in terms of understanding how well your system can do in dealing with some of the sort of the natural interference and noisiness in the sensing process and meteorological processes, perhaps you don't need to capture it at the resolution that your using in your modelling, in fact, you can get a pretty good bound on what the magnitude of the problem is by looking at a coarser resolution. I think as far as the gust front or other kinds of shear signatures, you have to face the problem that either .. you can take the time to detect shears that are hazardous, whether they are from microburst or other kind of phenomena, but you're still trapped in the situation of either saying, if you want to detect all the kinds of hazardous shears, then you better simulate them and assess your performance against the whole spectrum. If you're only interested in detecting microburst shears, then you still have to look at those other kinds of phenomena to see that you reject them and so I think it's difficult to assess the true performance and detectability or false alarmity of your system without considering a real spectrum of phenomena and what the system is going to do on that entire combination and I'm not sure you're getting there by simulating specific phenomena in the absence of all the other kinds of contamination that you're really going to see. Doing it against flight test data, it's great. But the thing you're going to have to face

up with then is what are you going to use as far as the ground truth data base is concerned. It's a great approach but there is a serious problem of understanding what was really out there when you collect the data.

Any other comments on that question.

Did we get everybody's questions, I think I've got them all here. Norm had a question, Q: Do you have plans to use your radar model microburst model to study TDWR placement strategies? If not, why not? A: Well, the answer to that is no,

we're not going to do that, it's not in our charter, we're looking at the airborne. Certainly the simulation program could be made available and if FAA wants to sponsor or somebody sponsor that activity that possibility of the radar simulation model could be useful, but it's not something we're going to be doing.

Herb, would you can to comment on that? At this point, I don't know of any plans for using the model in TDWR, Wayne or Jim could talk to it, but for one thing, it's a smaller domain size than what you're looking at, if I'm not mistaken for a placement strategy but anyway if you could get a microphone to Jim Evans who will make the proper response.

Well, we've been involved of course in this, there are a bunch of sites already being chosen. I think we take the contrarian view, I guess the answer we would say is over the last four years, we've probably measured close to 1500 microbursts and we believe that as far as understanding to the knowledge that we think, in terms of radar sensing we have a fairly good idea of what altitudes we want to look at and we're not convinced that we're going to learn anything at this point that would improve on the database from running a simulation. The other side of it is in terms of the ground clutter and it's predictability, I think the grazing angles we're talking about are very close to 0 degrees and there's a very large database of ground based measurements at those kinds of grazing angles and practical experience so again, we don't see that as being a practical factor. Thanks Jim.

Jim, I was trying to address the other problem of if you put the radar at the end of the runway, looking up the glad slope, you put it X miles away so you can surveil a bigger terminal area

The strategy that the FAA is utilizing which is a proper topic I guess for tomorrow is been to sight off the airport and in fact work at achieving the kind of timely warning that we heard a plea from a few minutes ago which was by being able to look a loft, you would be able to see things coming down and in fact issue warnings well in advance and in the case of TDWR the users, the requirement we're working at is to provide a one minute warning to pilots before they encounter a hazardous wind shear condition and if you think that's by and large been held up in the major of experiments today and we'll have a chance to hear about that tomorrow.

Let me go down the list of speakers, Ernie.

This is Ernie Baxa and I have several questions. I will make an attempt to respond to what I can and then I'm going to refer to Brac and Les Britt, because I think some of them are model questions.

This first one is from Jim Bull, Q: **Azimuth side low** clutter can appear at all velocities of interest, have you computed the clutter to signal ratio for **side low clutter** from **azimuth side lows** for practical antennas say a 28 inch antenna at x-band. A: The figure that I had shown was a figure to indicate some qualitative aspects of clutter, to answer the question I guess, succinctly yes, side low clutters included in model and I think Brac could probably elaborate on it just a little bit.

Yes, we have done some analysis looking at a 30 inch antenna and this information was shown in an earlier paper this morning but it does indicate the side low levels. This one is spectrum at a particular range bend, I think it was 4 1/2 kilometers from the aircraft. The aircraft was at 5 kilometers from touchdown and the main clutter with a 0 degree tilt was right, this is the main beam clutter right here, it is real spiked though here with some side lobe energy falling off, now actually there's energy much lower down if we could extend this scale down, you'd see energy going further and

further out but the energy is so low that really beyond when it gets down to this relative to the peak, it doesn't contribute a lot. When you tilt the antenna up by 2 degrees you can see that the main beam goes from way up at some 50 db here goes way down to about 5 db but the side lobe energy gets shifted a little bit in frequency but doesn't, is not changed a lot. Over on this other plot over here, we're pointed off at an azimuth of 10 degrees, and again, this is the main beam energy coming right through at this point, when you tilt it down, the side lobe energy, it doesn't change much but we have looked at the side lobe energy and the clutter to signal ratio and it does get included in the simulation program.

Jim, do you want to make a comment?

This is Ernie Baxa again, I have a question from Howard Long at Delta Airlines. Q: How do you expect to automate wind shear detection so that little or no operator time is required? A: I can't really answer that question directly. What I wanted to say though is from a signal processing point of view, what our main concern is to provide what I would call a statistically efficient as well as a computationally efficient statistic that is also a sufficient from a standpoint of wind shear detection and/or wind shear prediction and how that is used is really to be communicated to a pilot or to someone who is going to have to take action is really a different matter from my perspective. Would you like to comment further on your question or concern. I think that's a question a lot of folks are certainly interested in and there have been other papers that have discussed that.

This is Herb Schlickenmaier, FAA, it gets back a bit back to what Dave Carbaugh was talking about on how one integrates the human factors questions into the systems design and that's paramount, absolutely. It's not these guys jobs.

I certainly don't want to give the impression that I think it's a minimum problem or a non-problem. A couple of questions from Jim Evans, I will make some comments but I think Brac and maybe Les might want to comment too. Some of this has already been talked about in responding to earlier questions. Q: Why doesn't the clutter spectra show frequency components over the full unambiguous philosophy range? Clutter velocity is 0 meters per second for clutter well in the front of the aircraft, 60 meters per second below aircraft and 120 meters per second well behind the aircraft. This would after .. this should be aliasing I believe, extend over the entire frequency band. A: I think we've addressed that in answering Jim Bull's question. Yes it is distributed. Do we need to elaborate on it? It is all relative to aircraft velocity that was the basically the ground speed, that was the 0 on the Doppler spectrum.

Next question is also from Jim Evans. Q: Have you considered the loss in sensitivity due to attenuation of the weather signal by the notch filters in your simulations. This would be particularly significant with a **one pole canceller** if you are to achieve 25 db clutter suppression. A: Yes, the model the analysis that goes with the model that Dr. Britt, Les Britt from RTI have been working with, does in fact compute the attenuation of the weather signal. It's not at the present time included in the model that I have been working with at evaluating filters but it will be and is certainly a significant matter. The issue here has to do with evaluating how clutter filters affect the quality of the signal, the information content of the signal or the power level really of the signal itself. That is an important consideration. What we have done so far had to do with estimating the mean and the widths of the spectrum, rather than the power levels on the sensitivity issue. Does that satisfy that?

The last question from Jim Evans, Q: Are the effects of transmitter receiver instabilities being addressed in your analysis? What is the level of these in current systems and what is postulated for proposed systems?

A: There's a comment with this magnitron transmitter receivers generates substantive signal energy frequencies which would be in the past band of the clutter filters you have described. I want to make one comment and I want to ask Les Britt to make a comment about what's in the model. Presently I have a student looking at the effects at phase jitter on the pulse pair instrumentation procedure but basically going back and accounting for phase jitter looking at a phase jitter spectrum and one of our thrusts in this analysis was to create a set of specifications that would be appropriate for a radar system. That work has begun but is not anywhere near completion .. there's nothing I can really report at the present time except it is a messy problem. Les might want to say what's in the model at present.

In calculating the **I and Q** signals, this is the way they're calculated and this does have a term in that to represent phase error, which is a random phase term that is generated statistically in the model and changes for every pulse so that's in there. Now, the number that we've been putting in is a half of .. corresponds to a velocity or a mass of a half meter per second. This is the number we got from Varian Associates, talking about some of the stabilities of their transmitters. This is an input and one of the things that we're trying to determine the effects of, I mean, we're not building operational hardware, we're doing tradeoff studies that would hopefully come up with a spec, in other words, we'll determine the effects of phase jitter and then say the effect of it if it gets bad, so we're kind of working the problem the other way around. This is a parameter in the simulation. No, well I'll say it again, we're not building an operational system so the simulation is just a .. it simulates the transmitter with a certain phase jitter, you know it doesn't matter whether it's a magnitron, **clyston,** a solid state or what have you.

This is Bracalente. In our flight hardware that we're procuring for the experiment, we will not be using the magnitron because of this problem. Probably be using a TWT or a solid state for the low power version and TWT to get up to a couple KW which has much more stable frequency and phase characteristic.

Did that answer that question?

I would just make one comment, I think you'll find that they make amplitude errors as well and what wasn't clear and maybe you could put up on the board was whether this phase error is applied to the clutter signals. Is this formula the formula that's used to compute the clutter signal. A: Yes, this is as I said in the description of the simulation, the signal that comes from a particular range bend is a sum of population of random scatters and the phase term contains a term for transmitter phase error, a random variable which represents the phase jitter of the transmitter from pulse to pulse. (new speaker) Ok, so this formula is used for both weather scatters and ground clutter scatters. A: Yes, that's right.

Carrol Lytle, NASA LaRC. I have a question from Jim Evans, MIT Lincoln Lab. Q: Have you considered moving your roof top system to a location that is TDWR test bed measurement site which have frequent microburst activity and the requisite support sensors to obtain realistic microburst outflow back scatter data. A: As a short answer, yes we have considered it. Obviously the instrumentation we're talking about is the aircraft instrumentation and the first priority is to use this on the aircraft. Now we will be using it on the roof when we're not scheduled on the aircraft. We have considered what would be involved in taking this to someplace like Denver but we have made no commitment to engage in a program of that nature. The logistics of

sending someone out on site for an extended period. It's something we would like to do but we're not committed to it.

Pat, did you have any questions. Is Brian Gallagher, you've got a couple as well.

Dave Watt from the University of New Hampshire said that he will honest send us back all the written answers, he had to leave early and I would imagine Russ Targ will do the same.

The first question was from Jim Evans. Q: How does an infrared sensing system distinguish the cool air outflow of a gust front and that of a microburst. A: Right now, it doesn't. What we're doing is looking at the data that we can get and trying to see what we can do about it and when we actually get in the air, we'll be able to get a little better handle on that.

Second question is also from Jim Evans. This wasn't in the presentation today but a lot of the work that I'm doing and others in the infrared is doing is based on Pete Quenes work in the jaws. Q: The penetration of strong microburst outflows between 300 and 800 feet AGL is quite risky and has not been achieved on many microburst events. That is less than three at the most during the TDWR tests. Have the claim 42 low altitude microburst penetration during jaws been independently, that is by NCAR scientist confirmed? A: I don't know, I did go back and pull out the report. The data was taken on the 14 - 15 of July in the B57B. The systems that were up on that day was the busiest day in the entire jaws project where the 3 radars, the B57B, the King Air and so on, those come from the jaws final report. The jaws data shows 8 microbursts on the 14 and 21 on the 15. Out of the report from Quene and that's the NASA final report number which I did verify with Kerkowski who was in charge of that project with NASA Ames. He said there were approaches and encounters into shear conditions at Stapleton and vicinities in the jaws network and

the encounters were in the lower 100 meters so the answer to your question Jim, I don't really know. I did when I just got into this go to the NCAR people and others to try to substantiate where these microbursts were against the fly track and I had no luck in doing that. The project as I understand it was that the radars would indicate an area where the B57 should go to look for shears and that's exactly what they did. So, I guess the question is you need to talk to Quene, but I think the answer is that the correlation between the air craft track and the radars was not done on purpose. In other words, they weren't tracking the aircraft with the radar at the same time all this was going on. It was a very busy day and I couldn't get any correlation between the work that was done on the radars and the aircraft. Does that answer your question.

We tried flying planes in and around the Denver where there's microburst going on and I would be quite astonished that one would be that successful at flying along 100 meters above the ground through strong microburst and not getting into all kinds of problems with Air Traffic Control and everybody else in the system and as far as not knowing whether the airplane went near the radar, it's a little surprising that if this is a prime data source, I means NCAR people know very well where the microbursts were in location and as in L, as a function as time and I would presume that the aircraft people knew very well where it was as a function of time, that's why I'm a little astonished that nobody knows where the plane was relative to the microburst.

I can tell you, two things I know for use. I talked to Glen Stinet, who was the test pilot of that plane and asked him if he encountered a lot of microburst. He said he spend the entire day encountering microburst, going into them. You'll have to .. I can't answer the question past that and maybe Wayne could help verify it if somebody's willing to take the time and look at the aircraft track. The big problem was though was that the aircraft wasn't necessarily in the area where the radars were.

It was in and out of the area and was being vectored towards significant areas. That's the best I can tell you.

I guess I'm really prepared to answer the question in great detail on where the airplane was relative to the microburst for the B57, but I know in the case of the King Air, we flew through a great number of microbursts that summer but nothing at 100 meters AGL, I will confirm that because I did virtually all of those and so from King Air data I'd be surprised if there were any at that altitude, although there were quite a few at somewhat higher altitudes. The B57, I think had some lower altitude penetrations but I don't know the number but I'm sure that those data are available, I know Pat came looking for it and B57 data exists and I'm sure those people knew where they were. As did the jaws radar people know where the microbursts were so it's reconstructible data.

Yes, I guess the other point Jim is that that instrument was completely equipped with data recorders and the shears are very verifiable just from the aircraft data so you know I think it's a matter .. I took the information I could get and used it.

The other question was from Jim Bull at Boeing. Q: How much rain can your sensors see through? Isn't there likely to be rain before a microburst in some cases? A: Thanks to the folks at MIT, I asked them to give us an enroute approach set of numbers for how wet the microbursts were in both the Huntsville and Denver work and to make a long story short, it's was about 30 dbz on average for the wet areas and a little less then that in Denver. But also to show off what the low-tram would indicate for rain, there's a simple empirical equation for the transmission as a function of distance in rain and with one inch of rain you can look about 2 1/2 kilometers and 3 inches of rain about 1.18 kilometers. I also took out some of the data we calculated with the NASA provided models and what I've got here is the temperature profile as

sensed by an infrared sensor, ours at two different wavelengths. The temperature front he model is being sensed by the two different wavelengths. The 15 microns which is our near channel essentially rides right on top of the temperature in the model and 13.4 shows the advanced measurement of temperature and starts to go to very short distance or effective look path right about 3 inches per hour in the model. So the answer to your question, you could see at least a kilometer at 3 inches per hour and 2 inches per hour is read on the radar scope so does that answer your question. Thank you.

Mark Storm did you have any questions. Mark Storm will answer his questions if has any. Fair enough. Kioumars did you have a question? Dave had a question? Terry or Renee did you have any questions?

This is Dave Hinton, NASA LaRC, question for Mark. Q: Isn't there a big difference between following a stick shaker with a training aide versus not reaching stick shaker when flying the flight path angle? A: I'm not sure exactly what that means. I think that if you have two guidance strategies that exit the shear at the same altitude one flys 10 seconds of stick shaker and another one a void stick shaker there is a big difference. If that what you're .. operationally there is. The only qualification you have on that is that if the other strategy, the one that does not fly your stick shaker involves something that is counter intuitive to the crew, we have to face that training issue for it to be successful. Second question from Joey Sepi Q: With respect to conclusion No. 1 predicted benefits advanced recovery procedures may not be achieved or manually flown, how do you generalize your conclusion based on when recovery procedures to other advanced guidance procedures. Our efforts have shown that your conclusions are incorrect for at least one other guidance procedure. A: With respect to that, I underline the words may not, I don't say you that can not realize it, I'm saying that going from bad simulation to pilot simulations there are many factors that

must be taken into account or you may not achieve the benefits, that's what I was seeing in my results. One of my strategies of flight path angle strategy develops trajectories that look nearly identical to the trajectory shown in the slide on PC programs that Barrios did, where it will go to a target altitude level off fly path. Same type of results. When I flew that in the take off case recovery procedures across all the shears that I threw at it, it was statistically the same as the other procedures. There was one shear however, the strongest magnitude shear where that procedure was statistically better than any of the others. It was very, very tiny, so it depends on what you throw at it.

From Jim Evans at Lincoln Lab. Q: A very important element in your forward look reactor alert comparison is the assumed vertical profile in horizontal wind. The assumed outflow profile is very shallow compared to the assumptions made in the NASA Airborne Doppler Radar program where in they typically measure horizontal wind at 400 to 500 meters above the ground, which profiles view is appropriate? A: I think we answered it as a misconception of the 400 to 500 meter altitude that we've answered but I would like to mention that the analytic wind shear model I was using was not pulled out of a hat, that is it was fitted to an output from Fred Proctor's task program that was based on a sounding in Denver, 30 June 1982 and from that sounding he generated a series of microbursts with different rain shaft diameters and this was one of the smaller scale microburst that resulted from that sounding. Q: How would you result on benefits on forward look sensing have changed if you had assumed a much thicker outflow depth, that is with the winds down 50% from the peak level at 500 meters above ground level? A: I can't say for certain without actually doing it but my belief is not a whole lot for two reasons. One is that my energy hide analysis which I'm getting more confidence in as I test, the F factor was assumed constant across the shear regardless of altitude so there was no fall off of winds in altitude in that case. Secondly, I would expect that the Deltas, that is the

difference in performance with or without forward look would be slightly smaller for sure with stronger altitude but the trends would be the same, very nearly the same.

Howard Long has a question. Q: Do you feel that a forward looking system with guidance that provides a 5 to 10 second warning could provide equivalent safety to a reactive system with guidance? A: Good question, I'd like to give a qualified yes to that. The reason I ought to qualify it is that the exact numbers cannot be determined at this point. I have not tested in pilot simulations a 5 second warning so I can't say what would happen there. The second reason is that we would have to test that with a variety of shears and aircraft types to find out what those minimum numbers would be and a third very important thing to consider is that in my studies, the pilots know they're going to hit a wind shear and they react immediately upon an alert. When I give them a 10 seconds warning, there are times when they receive that warning and tell me in light of operation, I may not go around just yet because I haven't seen anything on my .. I have no reason to go around yet, I might think that was a false alarm. So whether or not they would go around with 5 to 10 seconds warning is really going to depend on crew training, displays if they can actually see what's in front of them, etc, so if they actually started to go around with 10 seconds warning, yes, you can achieve a quick level of safety.

Rob or Alex. Evidently they will answer their questions later in writing as well. Dave, you said you had a couple of questions. One question.

My one question, I mean I assume that's a misspelling on the Lockheed Alert, it should be a Look Ahead Alert, less than 11 seconds advanced warning to react a detection of caution positive energy enunciation or a warning negative energy in essence and the reactive alert was based on negative energy. That's it.

The point I was trying to make as part of the question was that if you did have a cautionary alert system based on the positive energy, that you could improve 11 second negative factor by some amount. Yes, but we didn't use a cautionary so I really can't give you that answer because I don't know. Anybody else?

And can you believe to finish this set up there's a guy by the name of Herb Schlickenmaier, is he any where in the building? From Norm Crayble, Q: Is the FAA's microburst policy that the pilot be provided with enough information to permit him to successfully fly through any microburst within it's capability and thus maintain airport acceptance rate or to avoid any microbursts which may pose an unreasonable threat to safety? A: the policy is avoidance. How one avoids a microburst is the purpose of the work that Jim Evans is doing and that Wayne is doing and the NASA team and I are doing which is to provide sufficient information for the flight crew and for air traffic to make reasonable estimates of the hazard and thus provide avoidance to the crew in a dynamic environment like a microburst that doesn't always happen as a discreet event, the mountain that isn't going to move in the next time an airplane comes by so it's not a binary event and the process of information that we're giving is continuous. Thank you very much folks on the agenda.

Session I. Ground Systems

TECHNICAL PRESENTATIONS

Thursday, 20 October 1988

Session I. Ground Systems

TDWR Program Status
A. L. Hansen, FAA

TDWR PROGRAM STATUS

A.L. HANSEN

FAA

TDWR Background Summary

- **Survey Of National Transportation Safety Board Data Indicates Wind Shear Caused Or Was A Factor In 149 Accidents Between 1975 And 1985**

- **Most Recent Major Accidents**

  - Pan American World Airways, Flight 759, July 9, 1982 At New Orleans (Take-Off)

  - Delta Air Lines, Flight 191, August 2, 1985 At Dallas (Landing)

- **System Requirements**

  - Provide "Timely And Accurate Detection Of Hazardous Wind Shear ... And Report This Information To Pilots And Local Controllers."

- **Research Between 1982-1984 Verified Use Of Doppler Radar With Algorithms To Detect Hazardous Weather (Including "Microburst") To Be The Best Available Method**

  - Data Provided To Pilots And Controllers To Require No Further Interpretation

TDWR

Differences From NEXRAD

- C - Band Frequency

- 1/2 Degree Antenna with Lower Sidelobes

- New Software Package

- Remote Maintainence Monitoring

- Better Data Decontamination

- Different Scanning Strategy

NCAR GSD

RANGE

5m 15m 30m 50m

SCREEN

1 2 3 4
5 6 7 8

MAPS

☑ Vortac & fixes
☑ ASR rings
☐ Airports
☐ Interstates

PRECIPITATION LEVELS

Off 1-6 3-6 5-6

WIND SHIFT:

Off On

DATE: 08/16/88
TIME: 17:02:23
PDATE: 07/11/88
MTIME: 22:08:03
GTIME: 22:04:01

WD: UP
GF: UP
PRECIP: UP
LLWAS: UP

45

35

7

5

3

9

5

5

NCAR GSD

RANGE
5nm 15m 30m 50m

SCREEN
1 2 3 4
5 6 7 8

MAPS
w/Vortac & fixes
w/ASR rings
□ Airports
□ Interstates

PRECIPITATION LEVELS
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PRECIP: UP
LLWAS: UP

45

35

1995 Terminal Operations

- TDWR at 47 Airports

- LLWAS at 110 Airports

- ASR-9 Weater Channel at 106 Airports

- AWOS at   Airports

- Mode S Data Link to Pilots

- AWOS/ATIS Broadcasts to Pilots

- Conversion to Advanced Automation System

TDWR

Where Do We Go From Here ?

- Continued R & D

  - Longer Lead Time Warnings

  - Improved Product for Pilots and Controllers

- Integration of Weather Data from Multiple Sources

- Artificial Intelligence

- Better Forecasts from NWS

Session I. Ground Systems

Low Level Wind Shear Alert System (LLWAS)
Craig Goff, FAA

LOW LEVEL WIND SHEAR ALERT SYSTEM (LLWAS)

BASIC CONFIGURATION

o SMALL NETWORK OF CONVENTIONAL WIND SENSORS AROUND AIRPORT AND AT CENTERFIELD.

o NETWORK SET UP TO DETECT LEADING EDGE OF THUNDERSTORM OUTFLOW AND TO PROVIDE
   FORWARNING OF OTHER HAZARDS IMBEDDED IN OUTFLOW.

o AVERAGE SENSOR SPACING 4KM.

o COMPUTE TWO MINUTE RUNNING MEAN FOR CENTERFIELD DIRECTION/SPEED.

o COMPARE PERIPHERAL WINDS WITH CENTERFIELD WINDS.

o SHEAR ALARM IF DIFFERENCE IS GREATER THAN 15KTS.

o DISPLAY ALARM DATA IN TOWER CAB.

o CONTROLLER PASSES INFO TO PILOT VERBALLY.

o PILOT MAKES MENTAL CALCULATION AS TO SIGNIFANCE OF SHEAR TO AIRCRAFT.

PROBLEMS WITH BASIC CONFIGURATION

o   DID NOT DETECT MICROBURSTS IN TIMELY FASHION -- NETWORK DENSITY.

o   NO SHEAR DETECTION CAPABILITY AT CENTERFIELD.

o   SENSORS OFTEN LOCATED AT POSITIONS AFFECTED BY OBSTRUCTION TO THE WIND
    -- INDUCED NUISANCE ALARMS

o   LIMITED AREAL EXTENT OF NETWORK.

o   DATA NOT RECORDED FOR LATER ANALYSIS.

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RESEARCH PROGRAMS

NIMROD   - 1978

JAWS -   - 1982

CLAWS   - 1984

COHMEX   - 1986

TDWR PROTOTYPE TESTING

LLWAS TEST BEDS

NEW ORLEANS - 1984

DENVER - 1985

LLWAS SIX-SENSOR IMPROVEMENT CONFIGURATION

o EMPLOYS WINDSHEAR AND MICROBURST DETECTION (WSMD) ALGORITHIM.

   - NUISANCE ALARMS REDUCED BY USE OF NETWORK AVERAGE AS REFERENCE.

o NEW PROCESSOR -- INCREASED CAPACITY.

o MICROBURST DETECTION AT CENTERFIELD.

o RECORDING CAPABILITY

RETAIN: 6-SENSOR CONFIGURATION .

   TOWER CAB DISPLAY (FIXED FORMAT).

LLWAS NETWORK EXPANSION CONFIGURATION

o   EXPANDED NETWORK TO OPTIMIZE WSMD ALGORITH M.

o   DISTINCTION BETWEEN MICROBURST SHEARS AND OTHER SHEAR TYPES.

o   RUNWAY - ORIENTED WINDSHEAR.

o   FLEXIBLE FORMAT TOWER DISPLAY.

o   TALL SENSOR MASTS WITH LIFT DEVICES

o   REVIED SITING CRITERIA.

LLWAS STATUS (12-15-88)

	E	C	TOTAL
PHASE I	0	44	44
PHASE II	57	1	58
PHASE III	2	0	2
PLANNED LLWAS	0	6	6
TOTAL	59	51	110

PROGRESS LAST 12 MONTHS (ENDING 12-15-88)

	E	C	TOTAL
PHASE I	0	8	8
PHASE II	57	1	58
PHASE III	2	0	2

ANTICIPATED RESULTS NEXT 12 MONTHS (ENDING 12-15-89)

	E	C	TOTAL	END
PHASE I	0	7	7	0
PHASE II	0	50	50	100
PHASE III	8	0	8	10

REMAINING 100 PHASE II LLWAS UPGRADED TO PHASE III IN 1990-93

LLWAS FUTURE WORK

o   3 Mile Extension

o   Interfaces to terminal NEXRAD and TDWR

o   Interface to terminal AT processor (TCCC)

o   Interface to Remote Maintenance Monitoring System (MPS)

o   Interface to Ground-to-Air Datalink.

Session I. Ground Systems

Terminal Doppler Weather Radar 1988 Operational Demonstration
Stapleton International Airport, Denver, Colorado
Wayne Sand, NCAR

TERMINAL DOPPLER WEATHER RADAR
1988 OPERATIONAL DEMONSTRATION
STAPLETON INTERNATIONAL AIRPORT
DENVER, COLORADO

By:

Wayne Sand

National Center for Atmospheric Research

Boulder, Colorado

PRESENTATION TOPICS

- Surface–based Wind Shear Detection and Warning Systems: LLWAS and TDWR.

- A Strategy for a Warning Message: Runway–Oriented Alerting.

- Microburst Algorithms, Validation and Operational Displays.

- Summer, 1988 Operational Products.

- New Directions: Integrated Terminal Weather Information System – Getting Critical Weather Information to ATC and the Cockpit.

- Conclusions.

Dry Air

Cloud Base
(As high as 12,000 ft.)

Virga or Rain

Downdraft

Outflow Front

Cold Air Plunge

Horizontal Vortex

Outflow

LLWAS Stations
Runways
Microburst
3 nmi
2 nmi
1 nmi
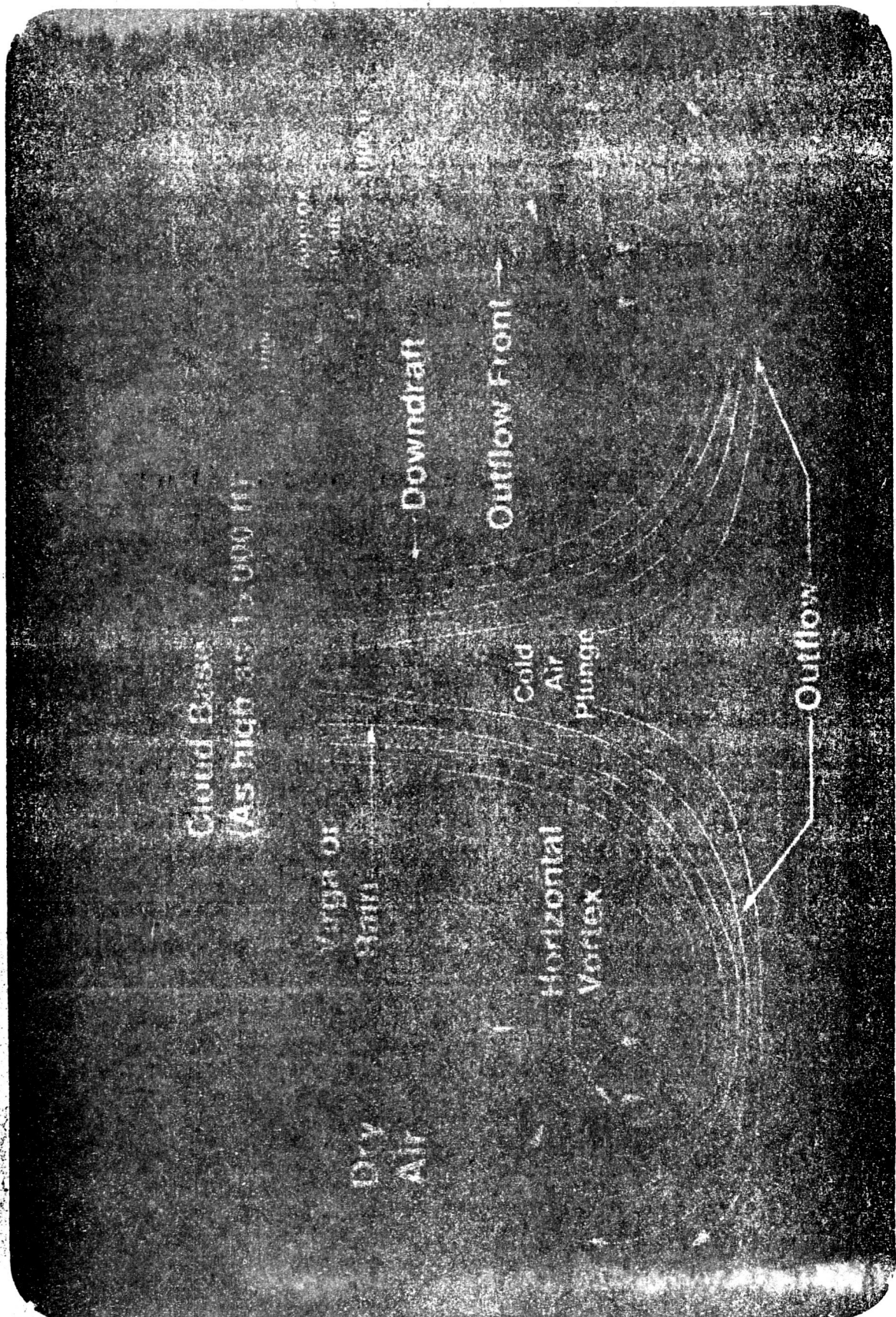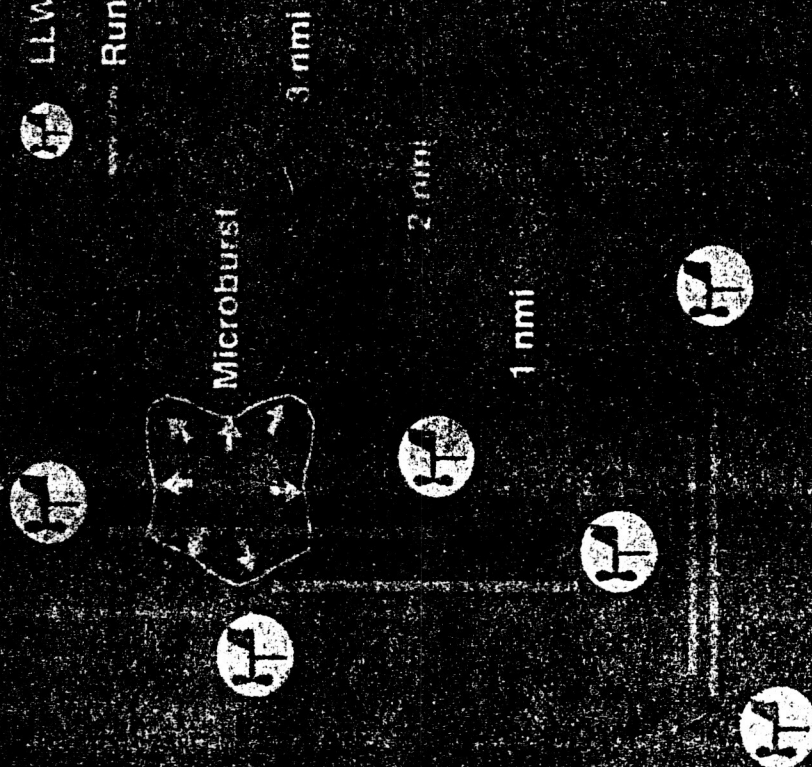
LLWAS WIND DISPLAY

	DIRECTION	SPEED	GUST
CENTER FIELD	180	15	25
N	180	5	
NE	210	27	
SE	330	10	
SW	040	6	
NW	140	22	
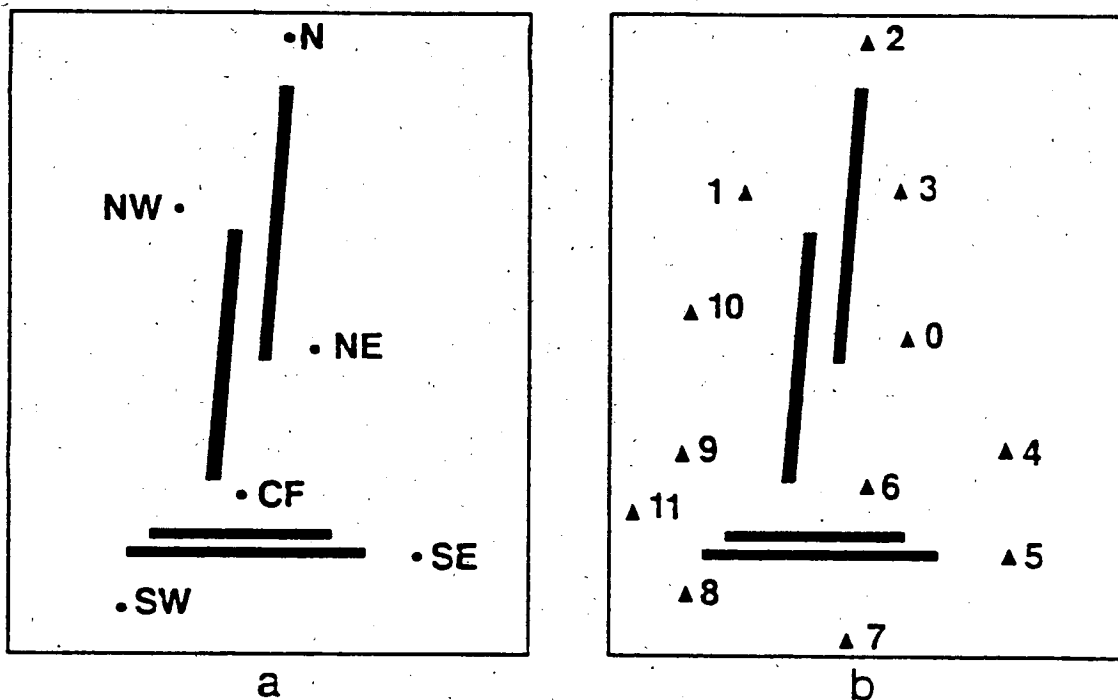
Figure 3. Illustration of the LLWAS at Denver Stapleton International Airport, showing a generalized array of wind sensors spaced around airport. Note that spacing is wider than typical microburst, resulting in many microbursts slipping through the "net." The system was originally designed to detect gust fronts rather than microbursts. (a) Shows the spacing prior to 1985, while (b) shows the spacing as enhanced to better detect microbursts. This improved spacing (b) is available at both Denver Stapleton International Airport and New Orleans International Airport. (Source: FAA, 1987a)
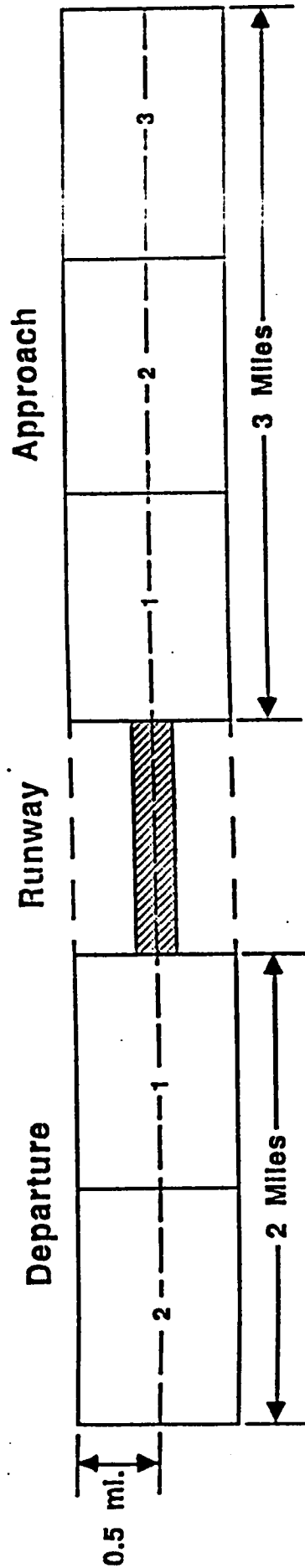
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TDWR Briefing Paper

Type of wind shear	Runway	Threshold winds			Wind shear Headwind change (kts)	Location
	CF	190	16	G 25		
MBA	35 LD	160	22		50-	RWY
MBA	35 RD	180	5		25-	RWY
MBA	35 LA	030	23		55-	1 MF
	35 RA	180	10		60-	3 MF
MBA	17 LA	180	5		25-	RWY
MBA	17 RA	160	22		55-	RWY
	17 LD	180	10		60-	RWY
MBA	17 RD	030	23		55-	RWY

694
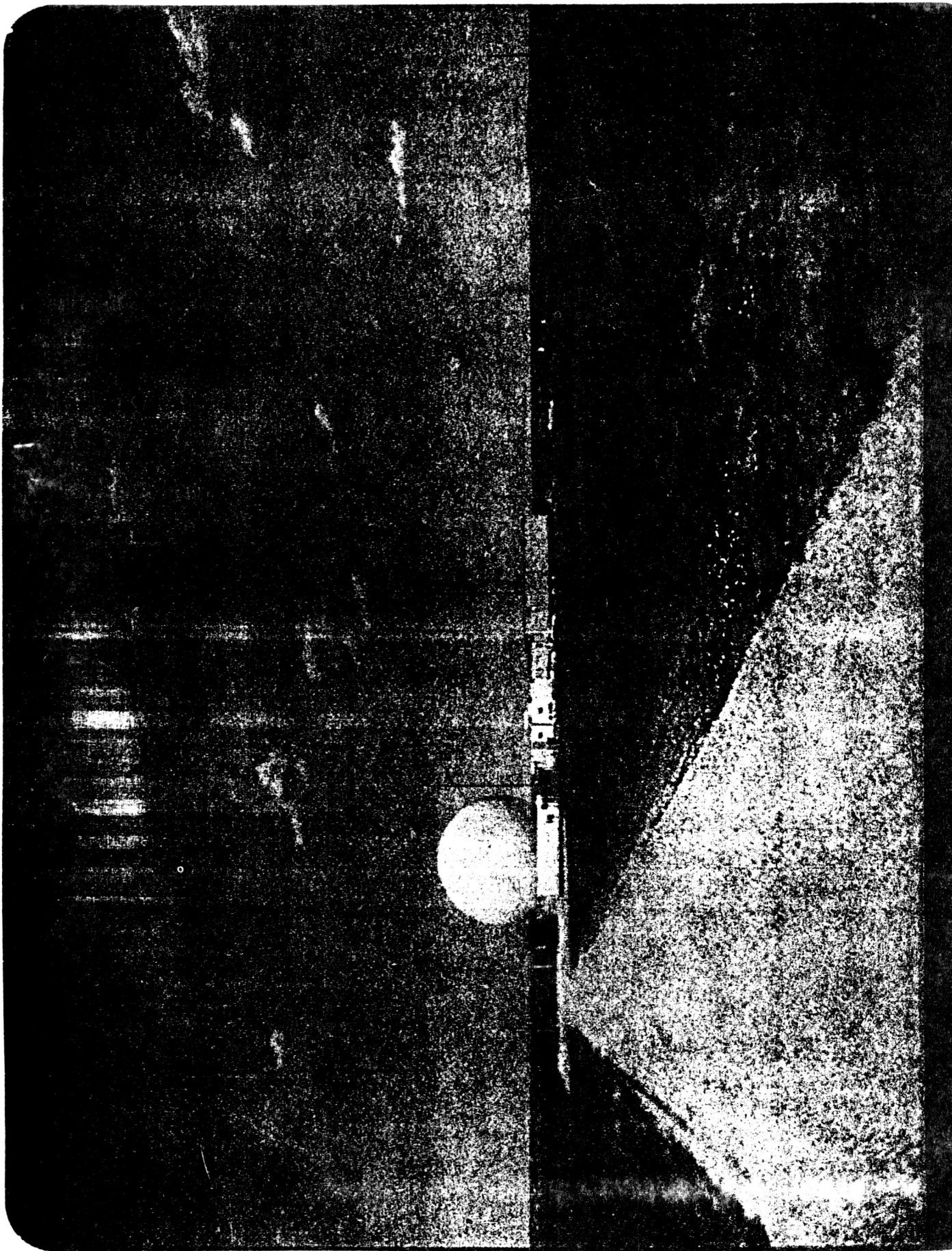
1987 DENVER MICROBURST POSITIONS

1987 DENVER MICROBURST POSITIONS

GEOGRAPHIC EVENT DISPLAY
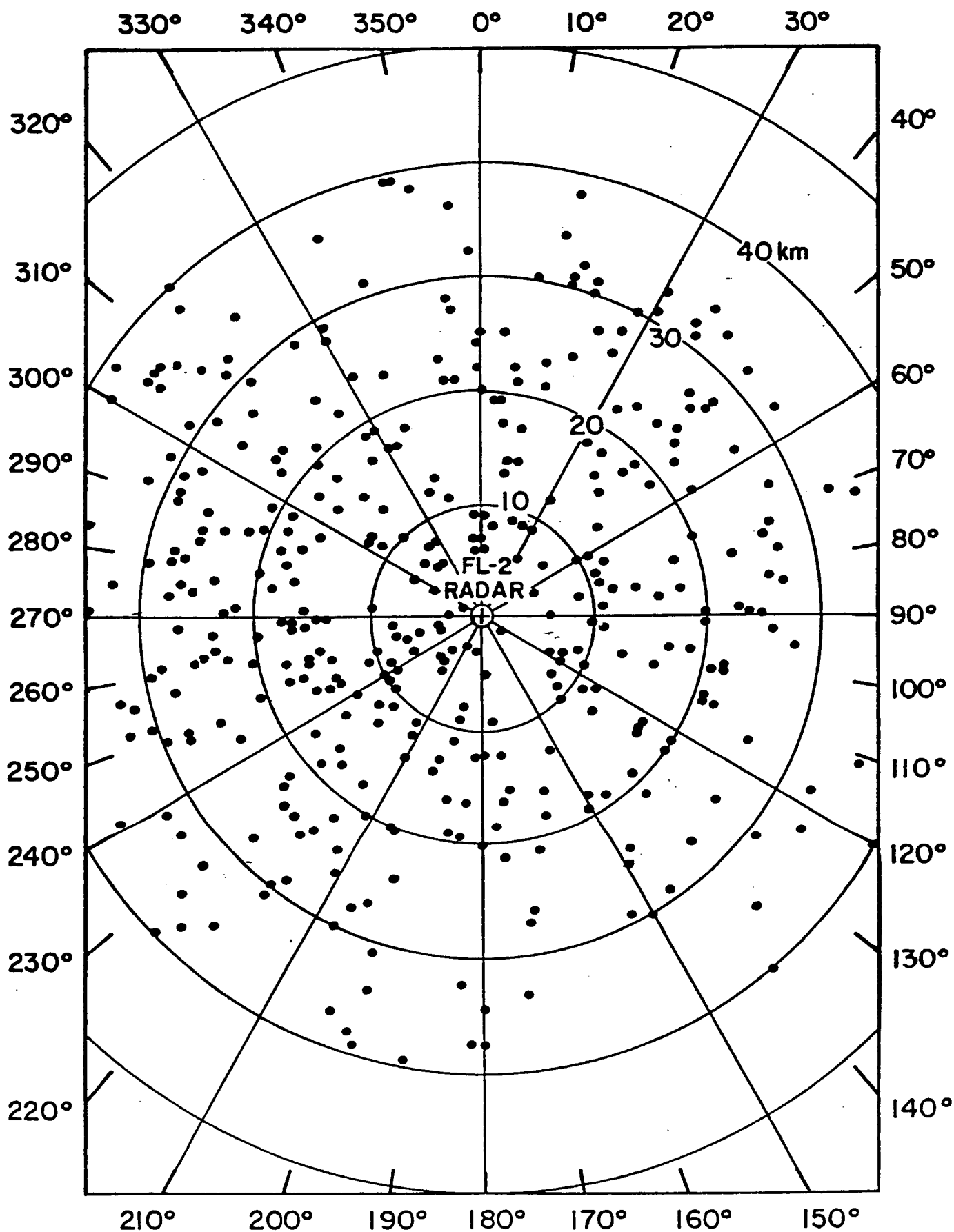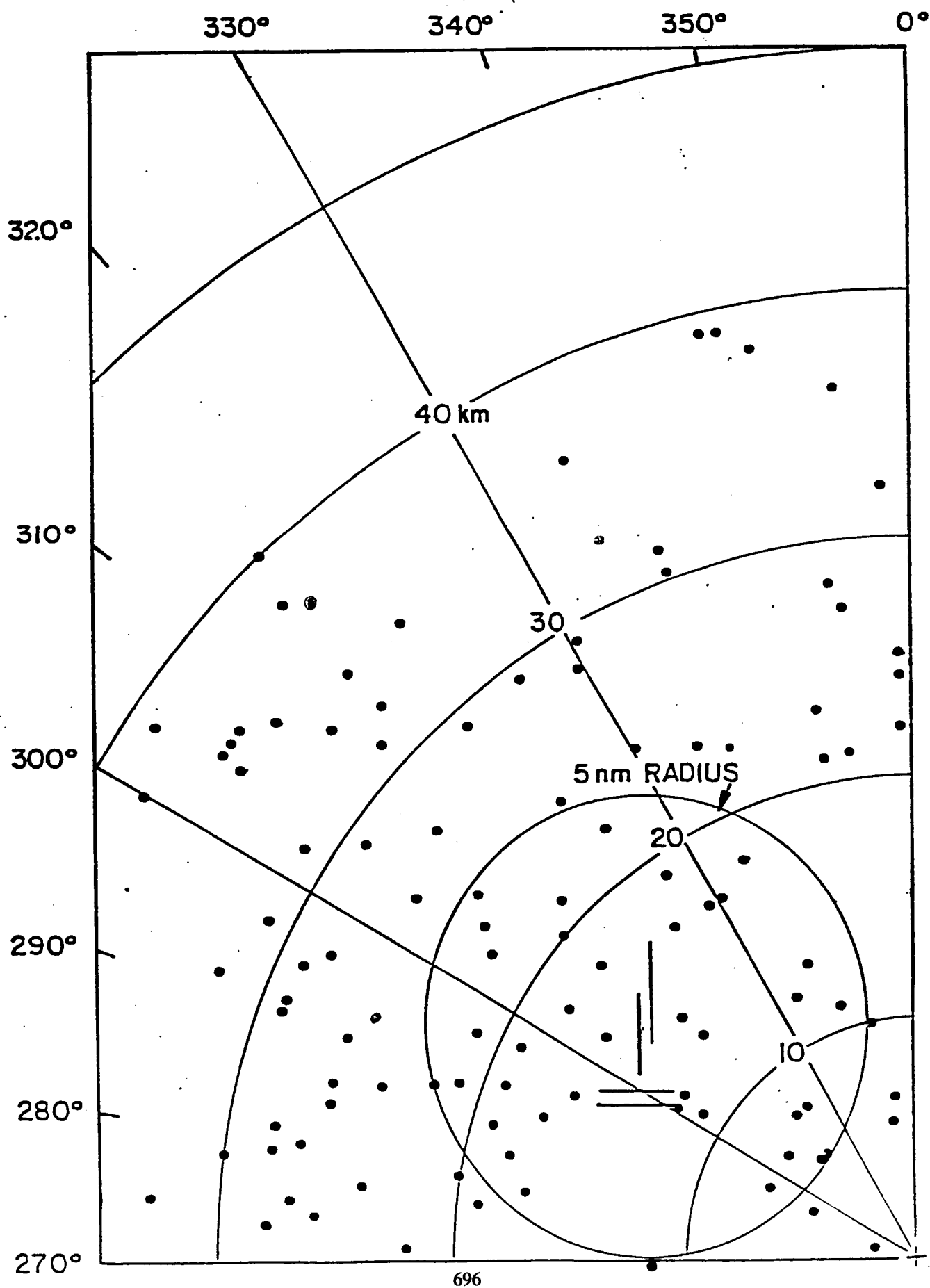
MODEL NUMBER = 1   TIME = 87 5 29 0 21 35

Microburst

699

C-4
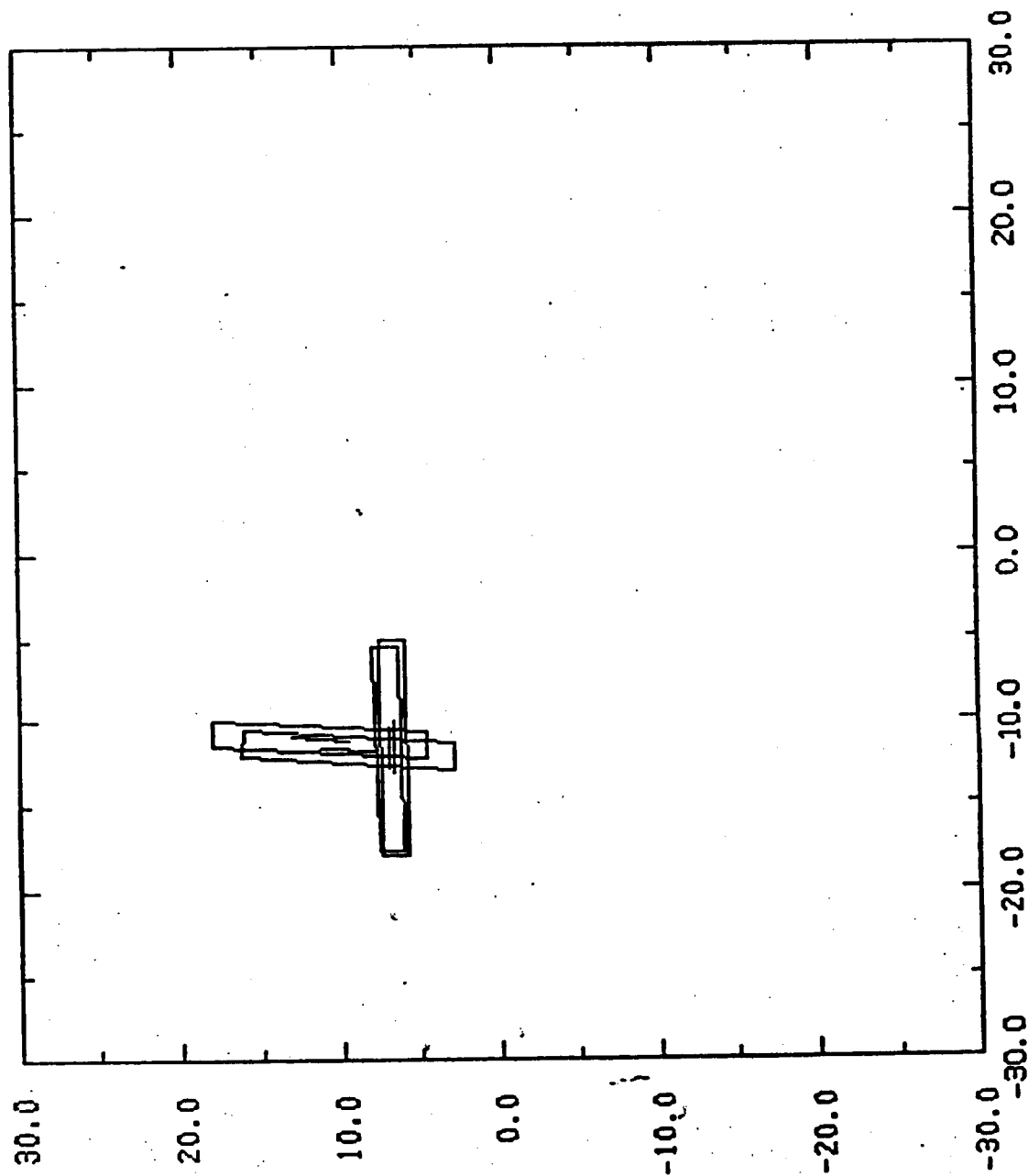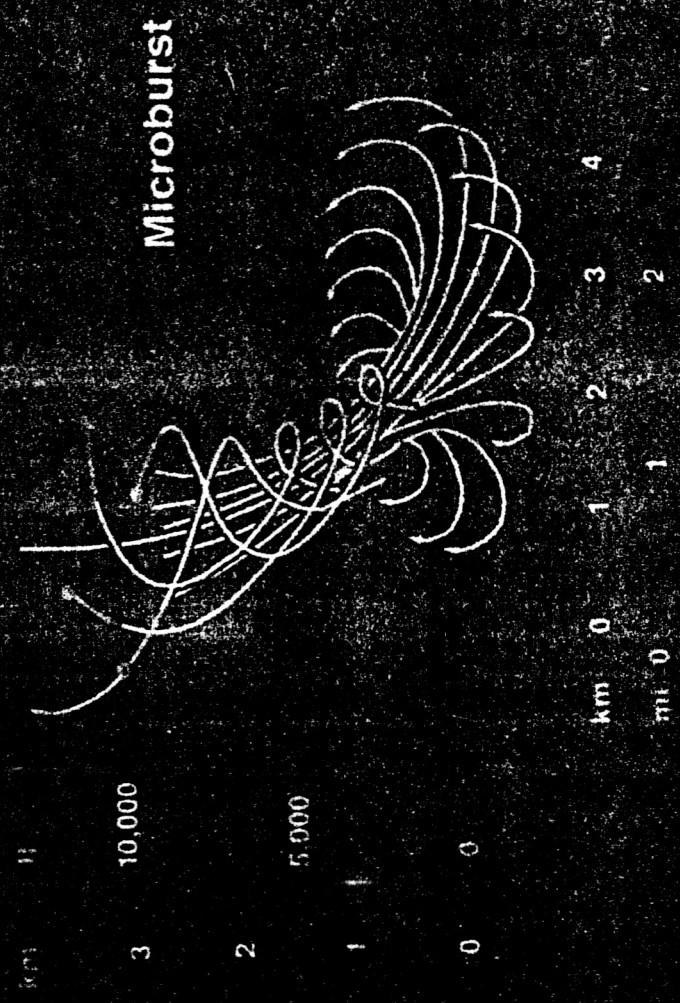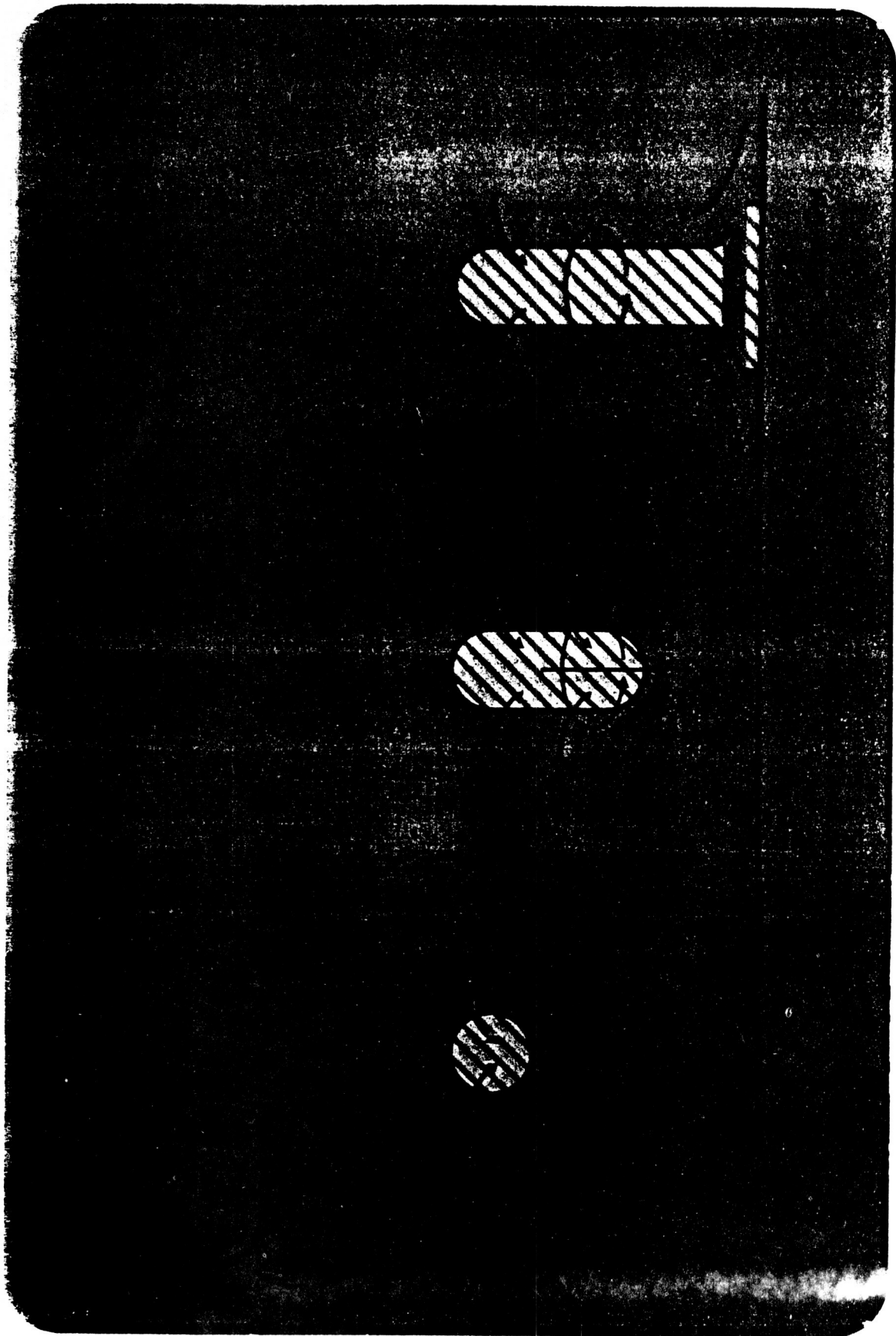
WIND SHEAR DETECTION PROCESS
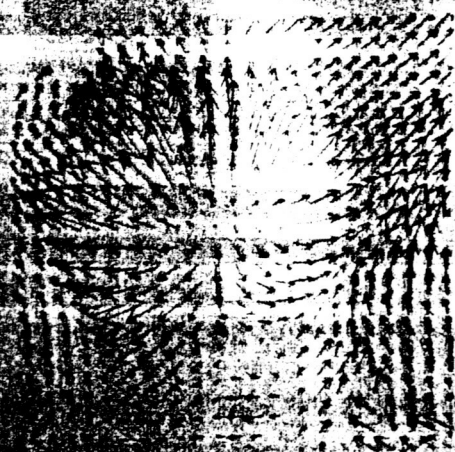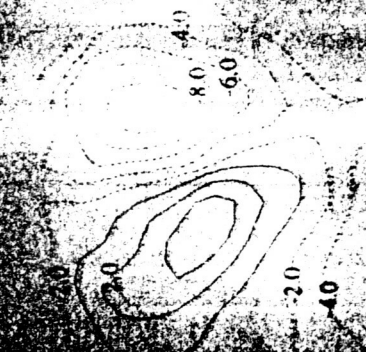
1. Radial velocity (Doppler Radar)
2. (Truth)
3. Wind Shear Segments
4. Feature Depiction
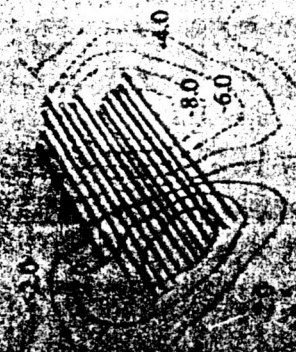
701
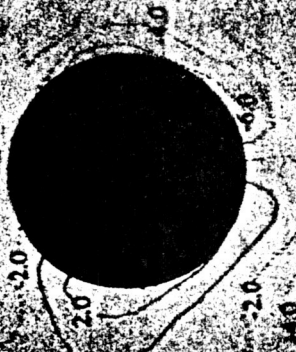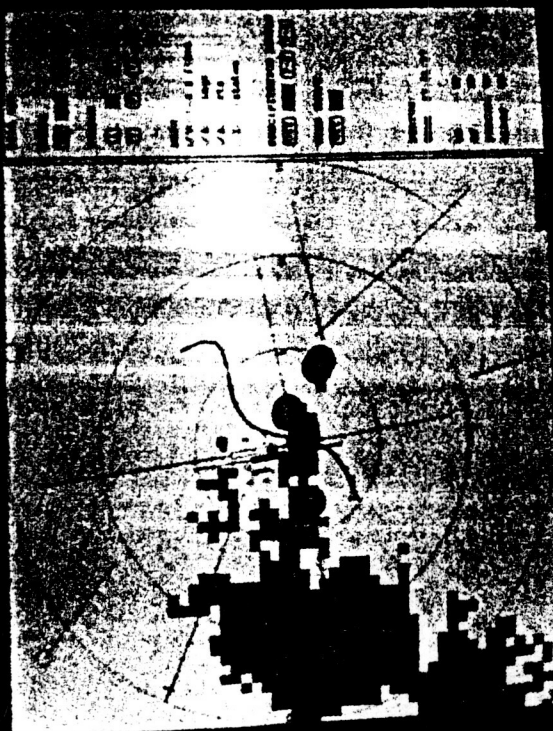
TDWR PRODUCTS

1988 OPERATIONAL DEMONSTRATION

- MICROBURST DETECTION*
    - LOCATION
    - INTENSITY

- GUST FRONT DETECTION*
    - LOCATION
    - INTENSITY
    - DIRECTION AND SPEED OF MOVEMENT

- WIND SHIFT PREDICTION
    - 20 MINUTE AIRPORT ARRIVAL WARNING
    - WIND DIRECTION AND SPEED BEHIND GUST FRONT

- PRECIPITATION
    - STANDARD 6 NWS LEVELS
    - HIGH RESOLUTION, LOW ALTITUDE PRODUCT NEAR AIRPORT
    - LOWER RESOLUTION, MEDIUM ALTITUDE PRODUCT NEAR GATES

---

* These products will generate microburst and wind shear warning

that will be provided to pilots.

RECOGNITION RATE BY TILT

Probability of Detection

| Data | Algorithm | POD | | | False Alarm Rate |
		< 40 kts <20 m/s	> 40 kts >20 m/s	Total	FAR
Huntsville '86	Surface	81%	100%	85%	3%
(3D)	Advanced	88%	100%	91%	5%
Denver '87	Surface	89%	98%	90%	4%
(3D)	Advanced	90%	99%	92%	5%
All Data	Surface	87%	99%	89%	4%
(3D)	Advanced	90%	100%	92%	5%

23 Feb 88
SDC

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ALGORITHM SCORING PROCEDURE

Radar Observations → Human Analysts → Compare

Radar Observations → Detection Algorithm → Compare

Compare → Performance Statistics

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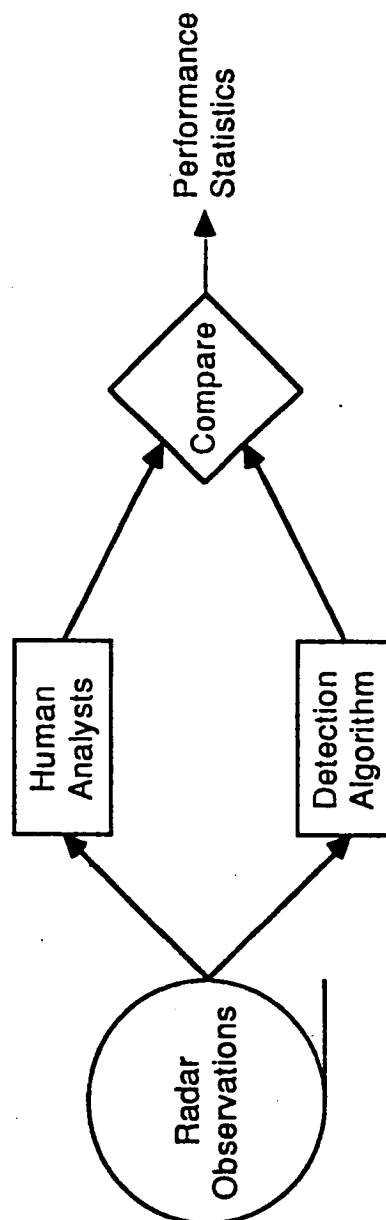
RECOMMENDATION REGARDING POSSIBLE FLIGHT OPERATIONS DECISION-MAKING AS A RESULT OF MICROBURST ALERTS DURING THE TDWR OPERATIONAL DEMONSTRATION

AVOID KNOWN WIND SHEAR – Guidance from the *Windshear Training Aid*. Consider the following:

- TDWR Operational Demonstration is expected to clearly identify microburst wind shear events at Stapleton, with a high probability of detection and a low false alarm rate.

- When TDWR identifies a microburst, there is a high probability that a severe wind shear is present.

- The *Windshear Training Aid* Guideline for recognition of a high probability of severe wind shear is:

  > THIS OBSERVATION REQUIRES CRITICAL ATTENTION. DECISION TO AVOID IS APPROPRIATE.

- Consider the development of a decision- making bulletin for Summer 1988 for Denver flight operations.

<div align="center">

EXCERPT

</div>

B-727 FLIGHT MANUAL - HANDBOOK

BULLETIN #

JUN XX, 1988

FROM: DENTK - FLIGHT STANDARDS AND
TRAINING

UA POLICY

During the conduct of this test, as is currently the
case, a "Wind Shear" alert must be given serious
consideration by the flight crew. All pertinent factors
relating to a planned takeoff or approach must be
critically examined before the specific course of action,
e.g., normal procedures, precautions, or avoidance
action is decided upon. (See Flight Handbook
Additional Procedures, Windshear Section)

A "Microburst" alert, however, clearly indicates that
avoidance action is required. A FLIGHT MUST
NOT DEPART NOR CONDUCT AN APPROACH
THROUGH AN AREA WHERE A MICROBURST
ALERT IS IN EFFECT. Delay the takeoff or approach
until the condition no longer exists along your intended
flight path.

A VARIETY OF RANDOM THOUGHTS BY JOHN MCCARTHY ON THE OCCASION OF THE REVIEW OF THE MICROBURST INCIDENT OF JULY 11, 1988

Some specific comments on the July 11th case:

The microburst algorithm did an excellent job in detecting the onset of the microburst, and apparently provided an alert sequence that accurately portrays the developing intensity of the event. Essentially, the system worked at least as well as we could have expected.

Controllers provided the five flight crews with the message as intended. It is unclear that the message impact is sufficiently clear, and a significant effort is necessary to address message impact, etc.

There was a significant variation in flight crew awareness of the program, in spite of substantial UAL effort to do so.

It would appear that wind shear recovery procedures were important aspects of a successful outcome.

Flight crews did not provide wind shear PIREPS, even though severe encounters occurred.

Human factor, information transfer, and training are the issues that dominate the action items.

Terminal NEXRAD Sites
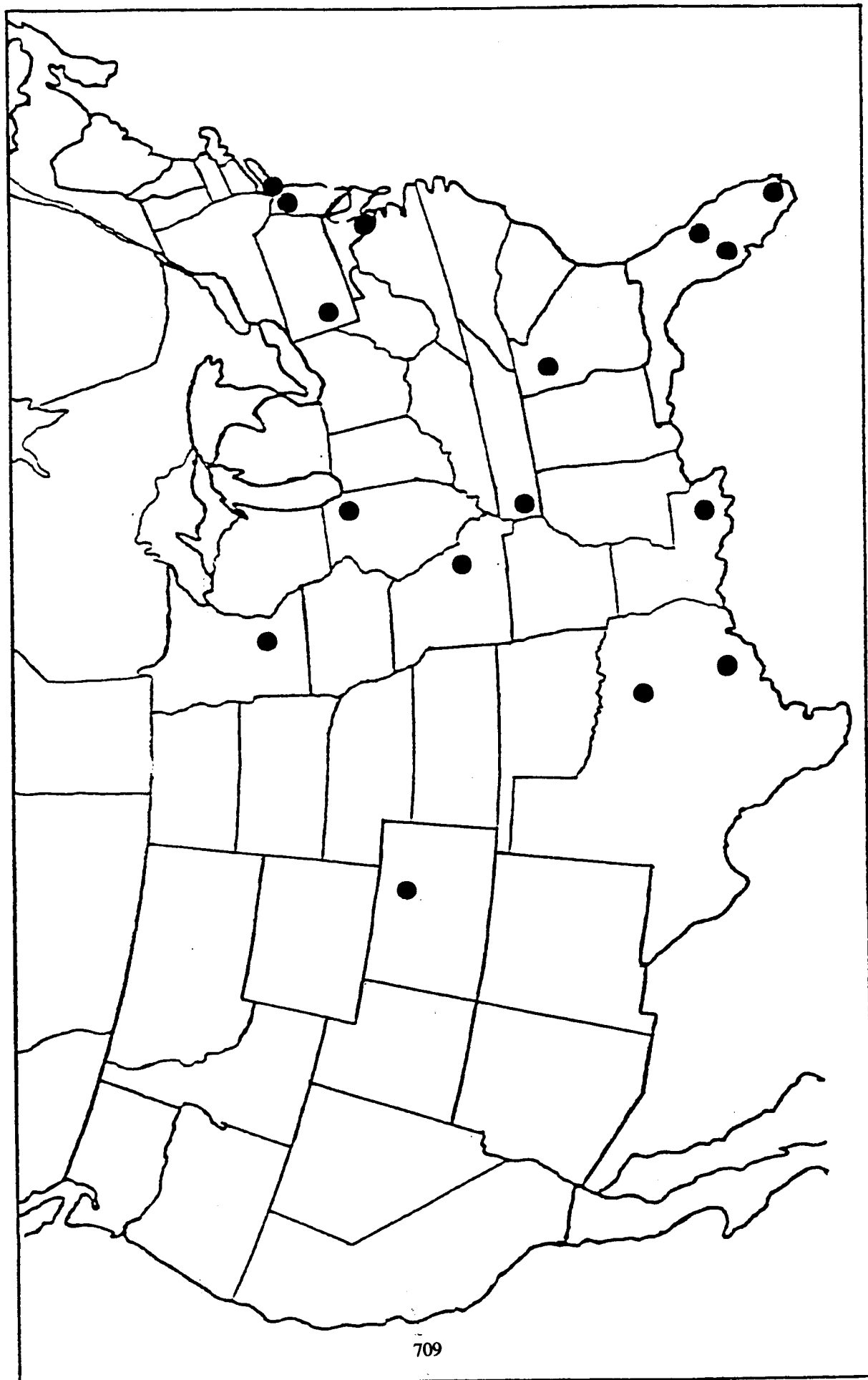
TDWR Sites
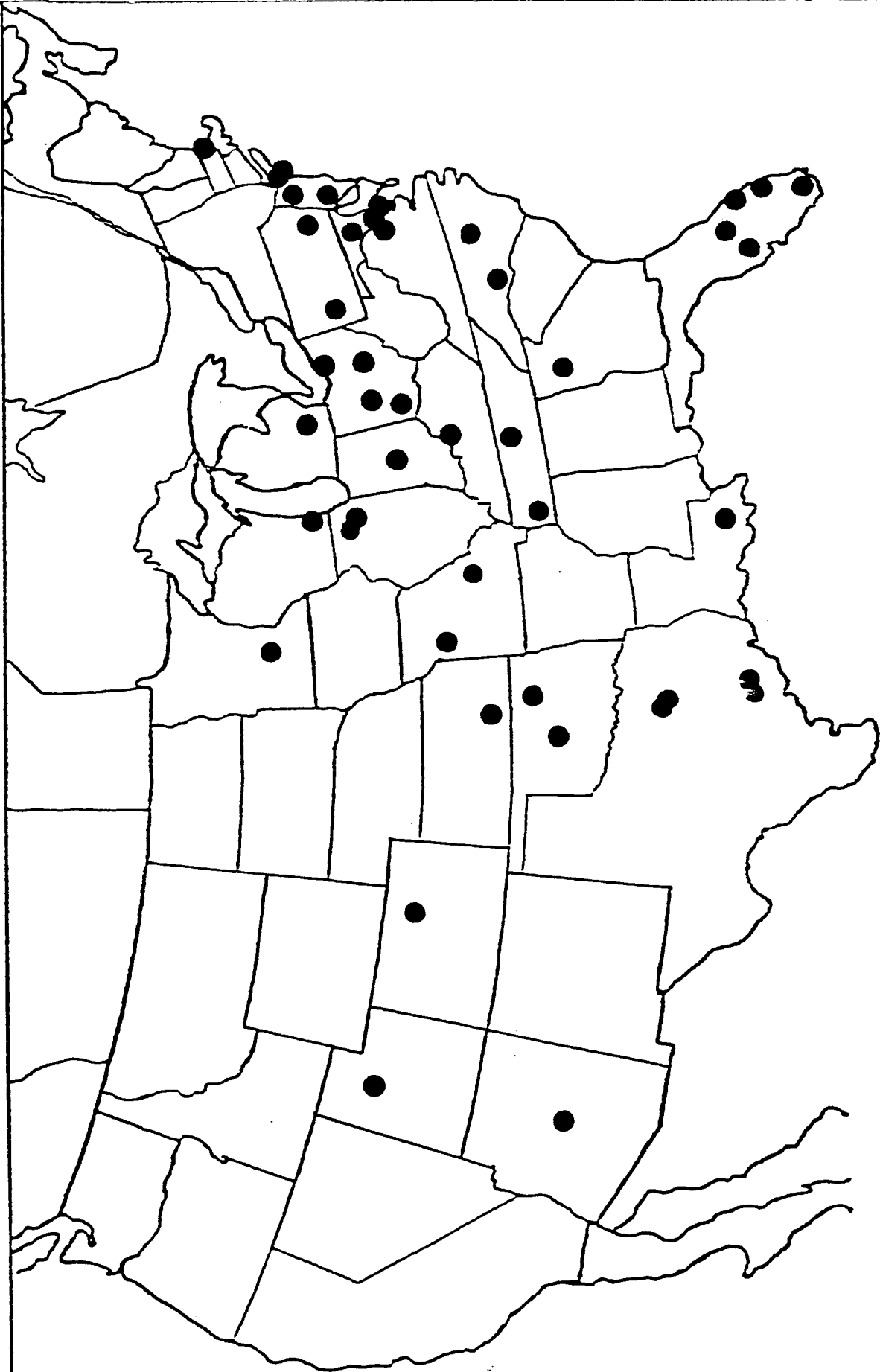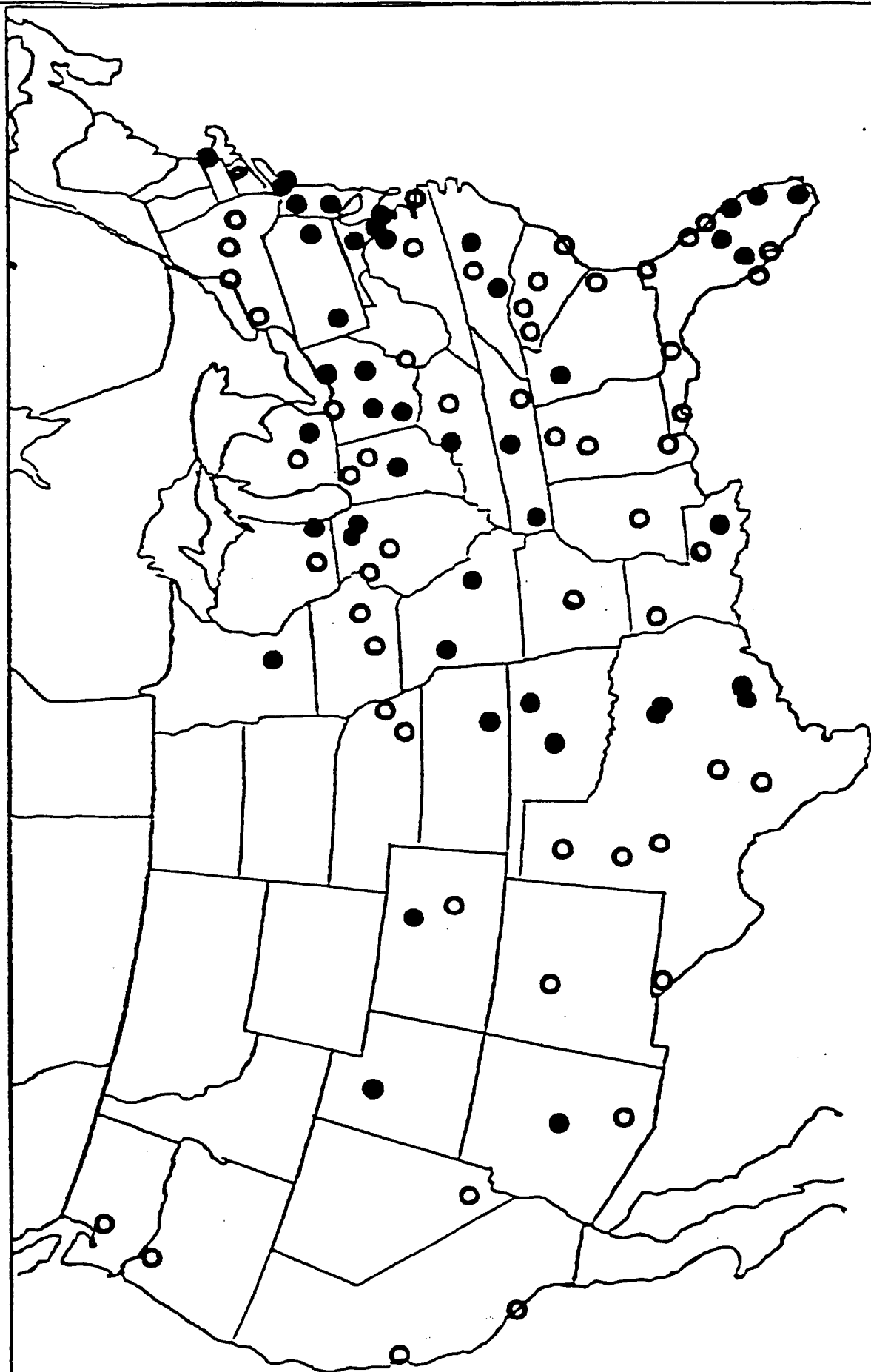
CRITICAL NEW DIRECTIONS FOR THE AVIATION WEATHER SYSTEM

Recommendation #1:

Vastly improved education and training for aviation meteorology.

Pilots

Aviation Weather Forecasters

Flight Service Station Personnel

Controllers

Revamp the Nature of Weather Training: R&D

Interactive, Impact-Oriented Exams

In-Depth Recurrent Training

Accountability in Training: Trainers and Trainees

Recommendation #2:

Continue efforts to quantify aviation weather hazards.

NEXRAD

Terminal Doppler Weather Radar

ASR-9

Enhanced Low-Level Wind Shear Alert System

Integrated Terminal and Enroute Weather System!

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Recommendation #3:

Enforcement of decision-making process in a quantified terminal weather system.

Today's cockpit avoidance decisions are mostly intuitive and are made without a sound basis in meteorological facts.

We must develop the means of enforcing avoidance when quantification of hazard has been fully established.

Controller makes the decision.
Pilot Flight Procedures Manual makes the decision.

INTEGRATED TERMINAL WEATHER INFORMATION SYSTEM

It is expected that the FAA will integrate information from three sources of wind shear information:

Terminal Doppler Weather Radar

Enhanced Low-Level Wind Shear Alert System

Weather Channel of the ASR-9 Radar

Ultimately, a single display system will be provided to air traffic controllers, in both the tower cab and in the TRACON.

Major NCAR Role: Validation
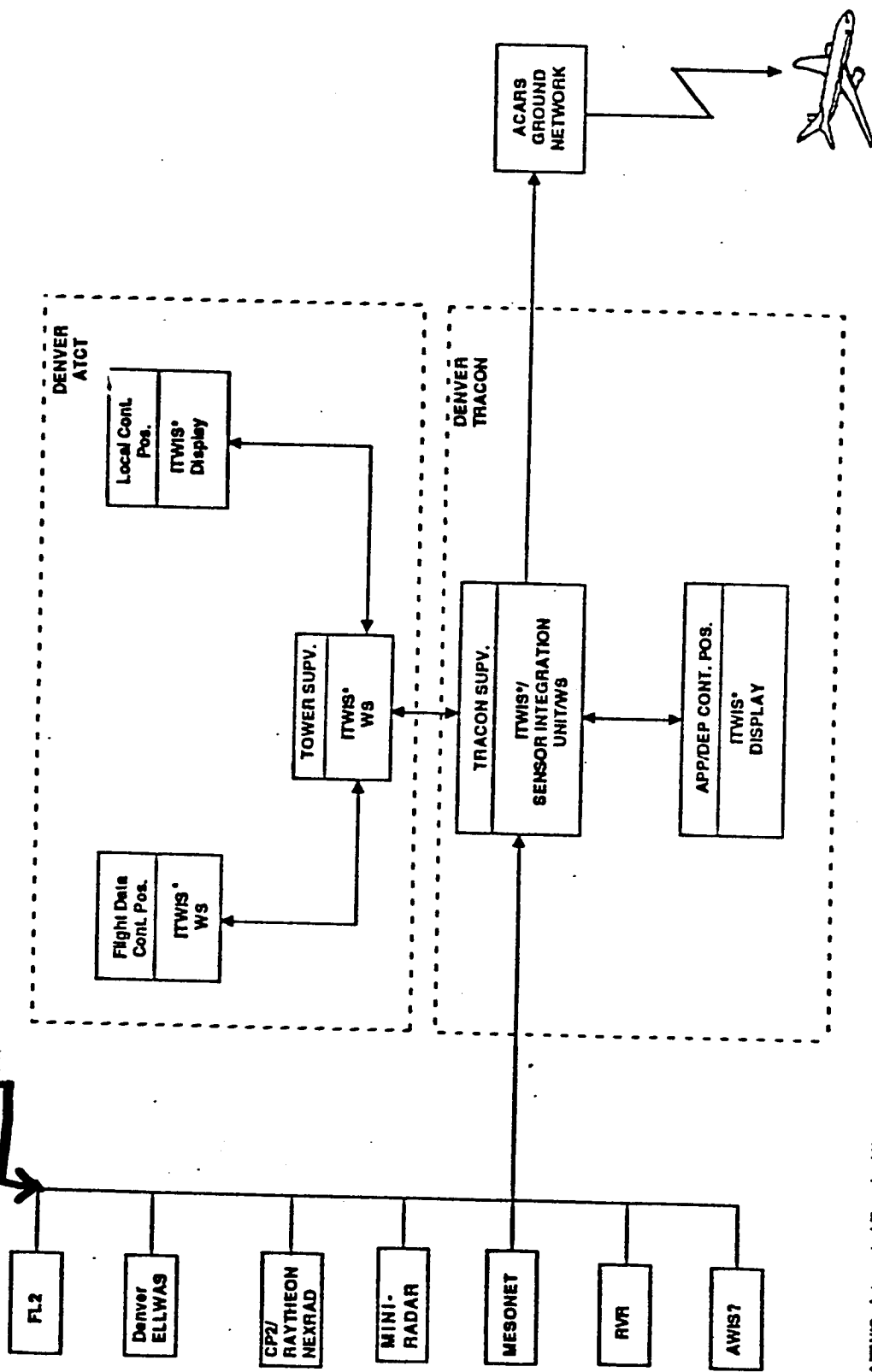
* ITWIS: Integrated Terminal Weather Information System

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Aircraft Performance in Wind Shear

- Ground based systems currently provide velocity differential (DV) in microbursts.

- We are examining the feasibility of measuring shear (DV/DR) as a hazard redefinition.

- Critical Question: Should hazard definition from a ground-based system be a binary (GO/NO GO) threshold?

    STRATEGIC VS TACTICAL DECISION

- Does a shear calculation invite flight crews to "THREAD THE NEEDLE?"

- Objective: To provide sufficient accuracy of wind shear hazard to provide "quality" go/no go decision.

- Should ATC be allowed to deny clearance to land or clearance to take off, once high quality hazard information is provided?

Information Transfer:
Human Factor Issues in Wind Shear Hazard Alerts

Assist FAA (Air Traffic Control–Aviation Standards) in sorting information transfer issues in hazard alert message delivery.

- Controller procedures, terminology
- Flight crew awareness, training issues

Airborne Wind Shear in situ Alerting

Validation with wind shear data collected by penetration aircraft, in conjunction with multiple Doppler weather radar analysis.

To what extent are the current generation of in situ sensor systems adequately validated?

MOTTO OF TERMINAL DOPPLER WEATHER PROGRAM

VALIDATION

VALIDATION

VALIDATION

Does this model apply to airborne alert system? If not, why not?

Session I. Ground Systems

A Cursory Study of F-Factor Applied to Doppler Radar
Kimberly L. Elmore and Wayne R. Sand, NCAR

A Cursory Study of F-Factor Applied to Doppler Radar

Kimberly L. Elmore, Wayne R. Sand
National Center for Atmospheric Research
P.O. Box 3000, Boulder, CO 80307

A Hazard Index: F-Factor

$$F = \frac{\partial \vec{V_x}/\partial t}{g} - \frac{\vec{w}}{\text{TAS}},$$

$\vec{V_x}$ = wind component along flight path,

g = acceleration due to gravity,

$\vec{w}$ = vertical wind,

TAS = true airspeed.

From Bowles and Targ, 1988

A Model

$$y = A \sin\left(\frac{\pi}{2D}x\right),$$

$$A = \frac{\Delta V}{2},$$

$$D = \frac{\Delta r}{2}.$$

To find the maximum difference between shear estimates based on $\Delta V/\Delta r$ and those based on the model, evaluate $\partial y/\partial x$ at $x = 0$:

$$\partial y/\partial x|_{x=0} = \frac{\Delta V}{\Delta r} \frac{\pi}{2} \cos(0)$$

$$= \frac{\Delta V}{\Delta r} \frac{\pi}{2}.$$

This is the maximum ratio between the two estimates.

The Least-Squares Fit

The least squares residual is given by:

$$R(\beta) = \int_{-1/2}^{1/2} \left[\beta x - A \sin\left(\frac{\pi}{2D}x\right)\right]^2 dx,$$

$$\beta = \text{slope of least squares line}$$

Least squares line given by $y = \beta x + 0$.

Minimize the residual:

$$R'(0) = 2\beta \int_{-1/2}^{1/2} x^2 dx - 2A \int_{-1/2}^{1/2} x \sin\left(\frac{\pi}{2D}x\right) dx$$

$$= 0.$$

Solve for β:

$$\beta = \frac{A \int_{-1/2}^{1/2} x \sin\left(\frac{\pi}{2D}x\right) dx}{\int_{-1/2}^{1/2} x^2 dx}.$$

Evaluate the numerator using integration by parts with $u = x$, $dv = \sin\left(\frac{\pi}{2D}x\right)$, $du = 1$ and $v = -\frac{2D}{\pi}\cos\left(\frac{\pi}{2D}x\right)$.

$$
\int_{-1/2}^{1/2} x \sin\left(\frac{\pi}{2D}x\right) dx = \frac{2D}{\pi}\left[-x\cos\left(\frac{\pi}{2D}x\right)\right]\Big|_{-1/2}^{1/2}
$$

$$
+ \left(\frac{2D}{\pi}\right)^2 \sin\left(\frac{\pi}{2D}x\right)\Big|_{-1/2}^{1/2}
$$

$$
= 2\left(\frac{2D}{\pi}\right)^2 \sin\left(\frac{\pi}{4D}\right) - \left(\frac{2D}{\pi}\right)\cos\left(\frac{\pi}{4D}\right).
$$

For the denominator,

$$
\int_{-1/2}^{1/2} x^2 dx = \frac{x^3}{3}\Big|_{-1/2}^{1/2}
$$

$$
= \frac{1}{12}.
$$

The Bottom Line

Solve for β, rearrange terms and substitute in ΔV and Δr:

$$\beta = 6\Delta V \left[2 \left(\frac{\Delta r}{\pi} \right)^2 \sin \left(\frac{\pi}{2\Delta r} \right) - \left(\frac{\Delta r}{\pi} \right) \cos \left(\frac{\pi}{2\Delta r} \right) \right].$$

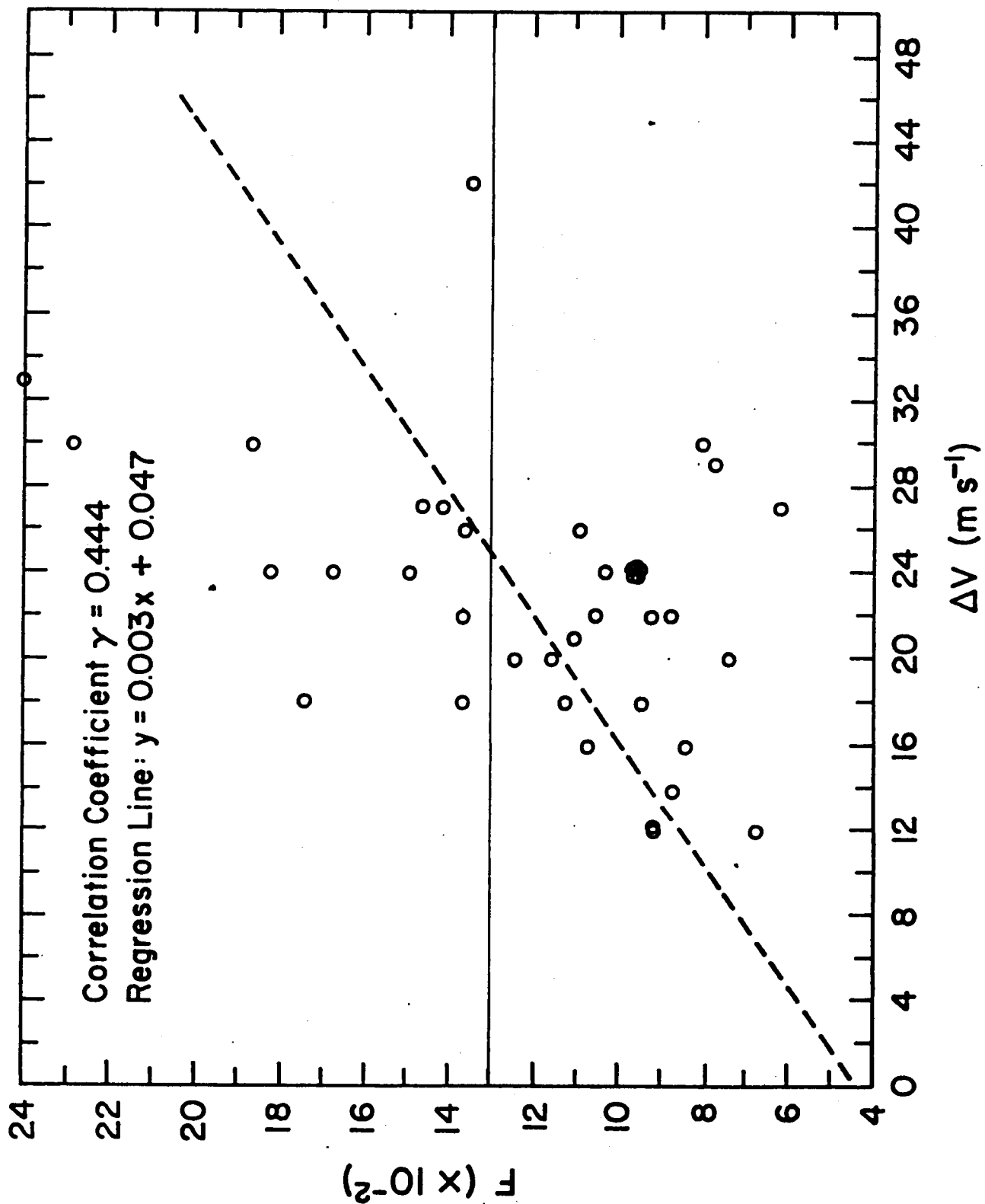β = shear in s^{-2} over 1 km least $-$ squares line fit to model.

$\Delta V_{1\,km}/\Delta V_{tot}$ VS. ΔR

Asymtote to $\pi/2$ (theoretical max)

$\Delta V_{1\,km}/\Delta V_{tot}$

ΔR (km)

733

F_x VS. $\Delta V/\Delta R$

Correlation Coefficient = 0.999
Regression Line: y = 11.024x + 0.444

F VS. ΔV/ΔR

Correlation Coefficient = 0.999

Regression Line: y = 14.922x + 0.005

ΔV/ΔR (10^{-3} s^{-1})

F ($\times 10^{-2}$)

735

F_x VS. ΔV

Correlation Coefficient $\gamma = 0.442$
Regression Line: $y = 0.002 x + 0.035$

ΔV (m s^{-1})

F_x ($\times 10^{-2}$)

F VS. ΔV

Correlation Coefficient $\gamma = 0.444$
Regression Line: $y = 0.003x + 0.047$

ΔV (m s⁻¹)

F (× 10⁻²)
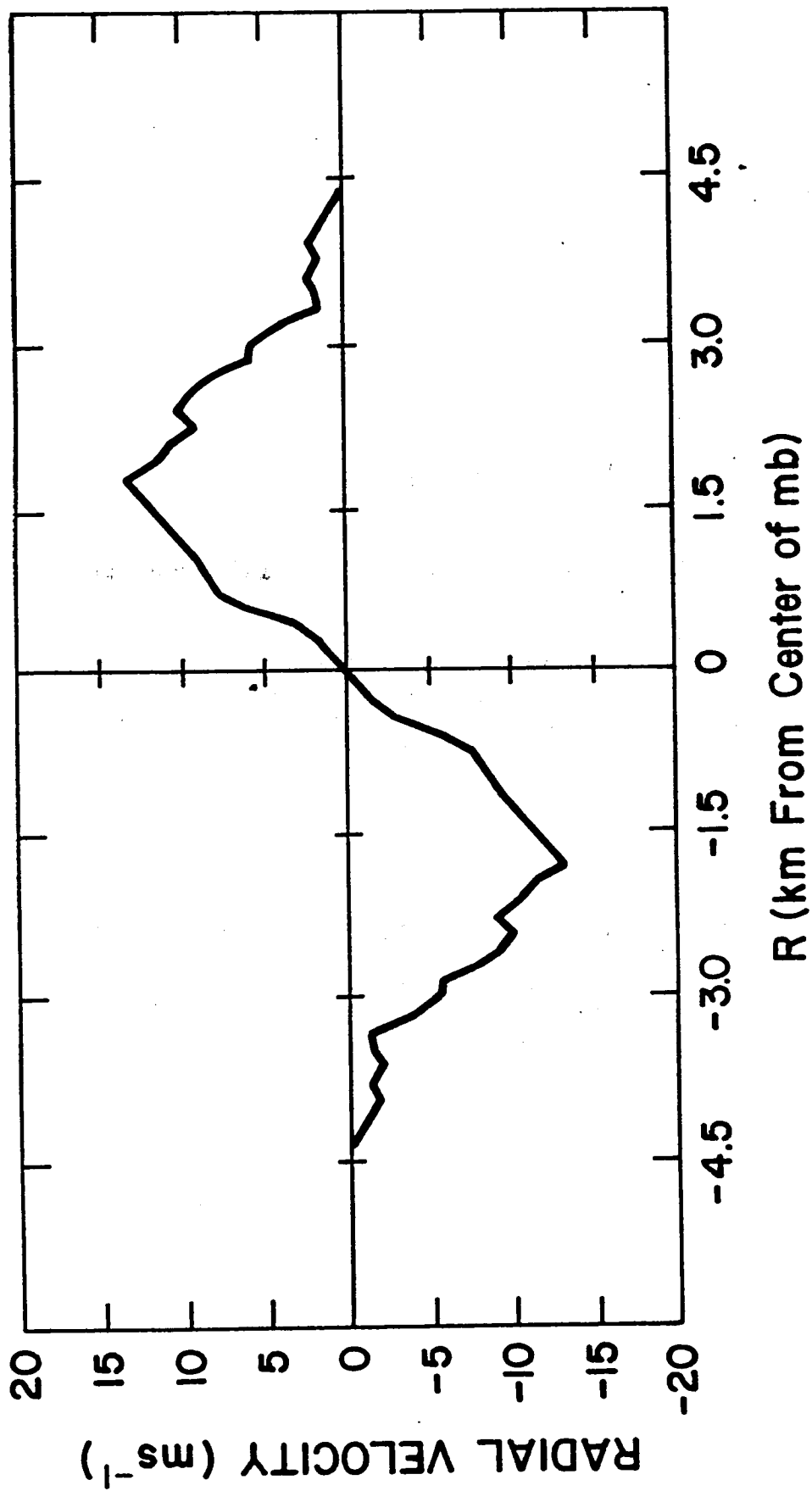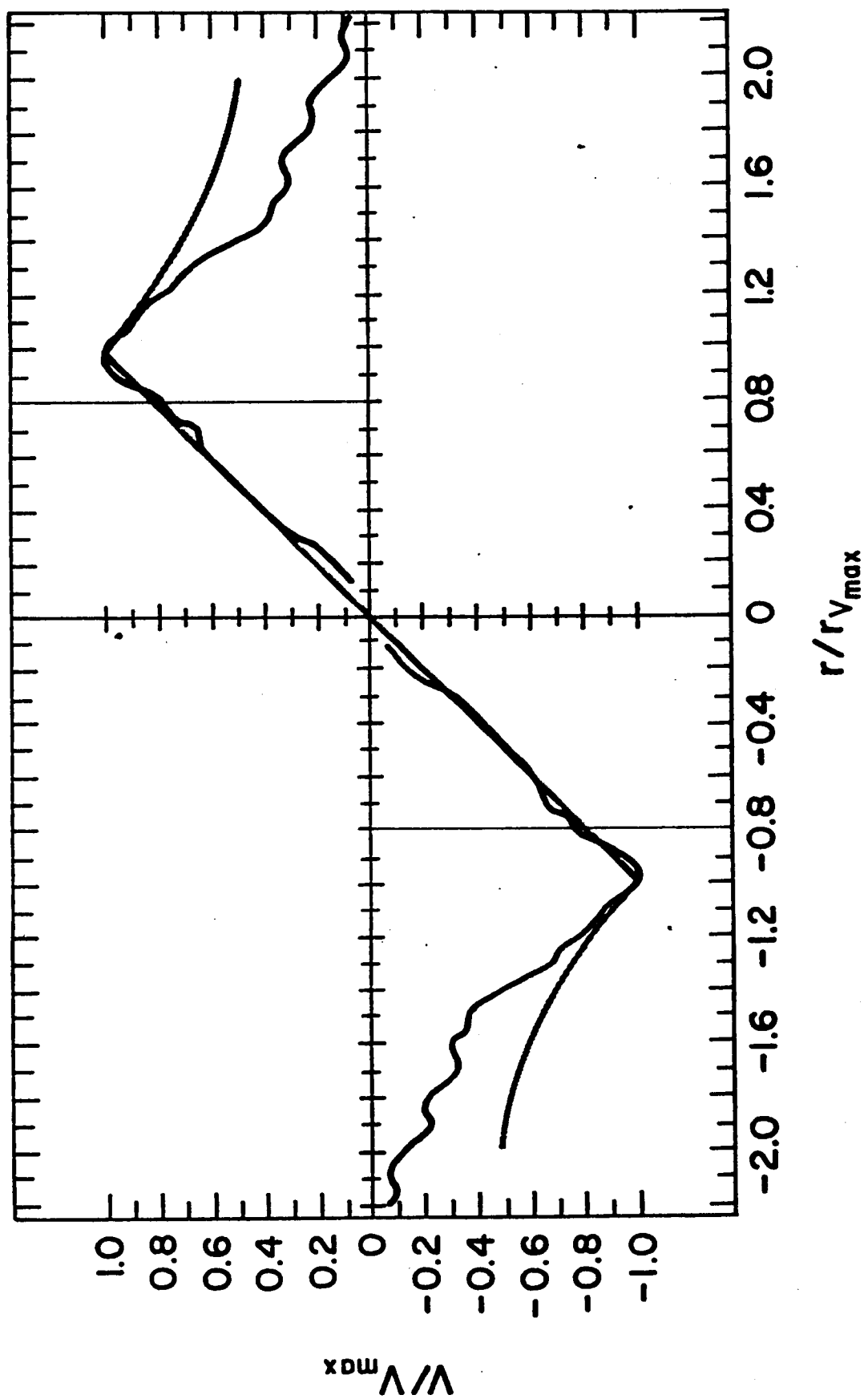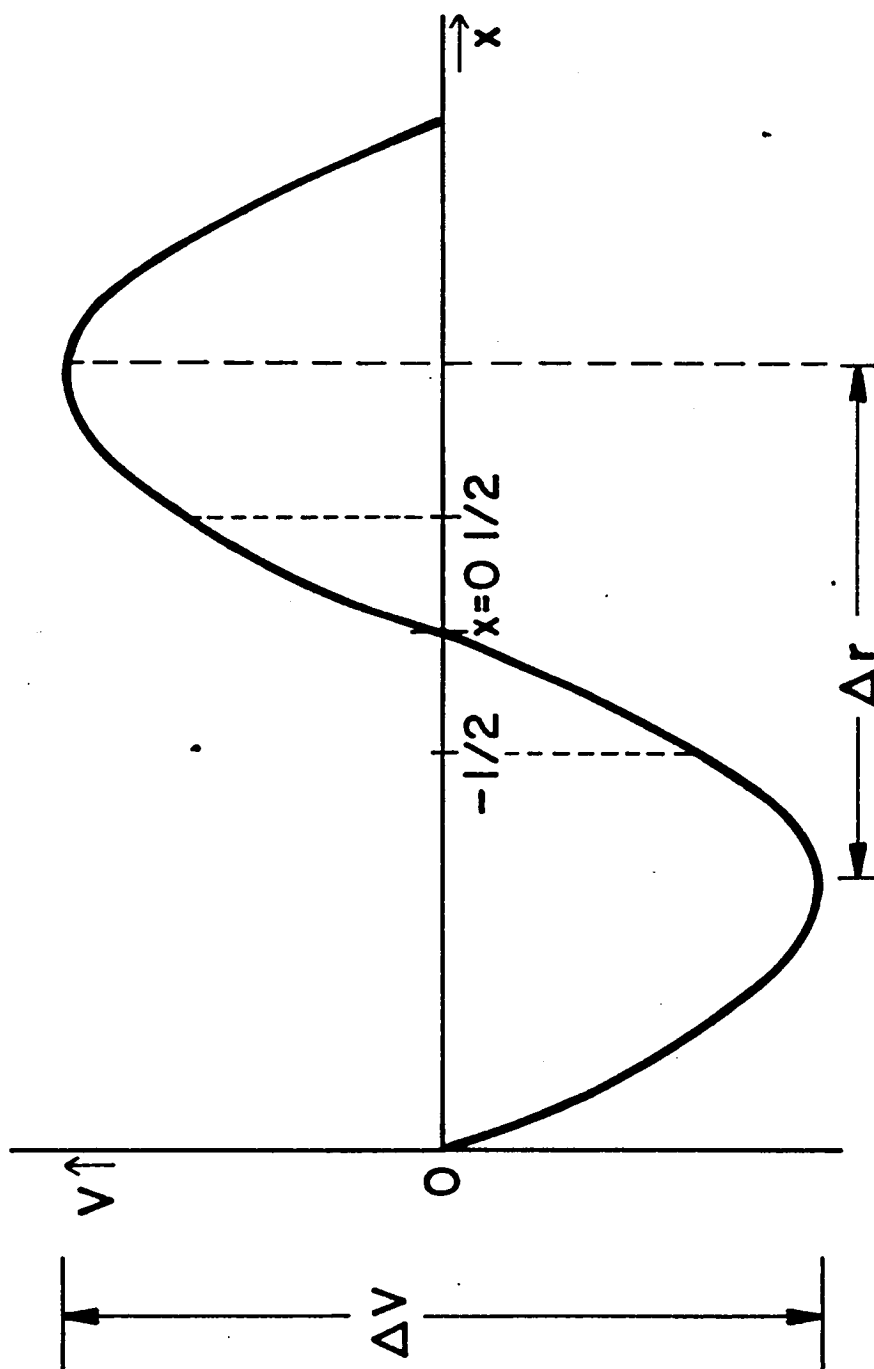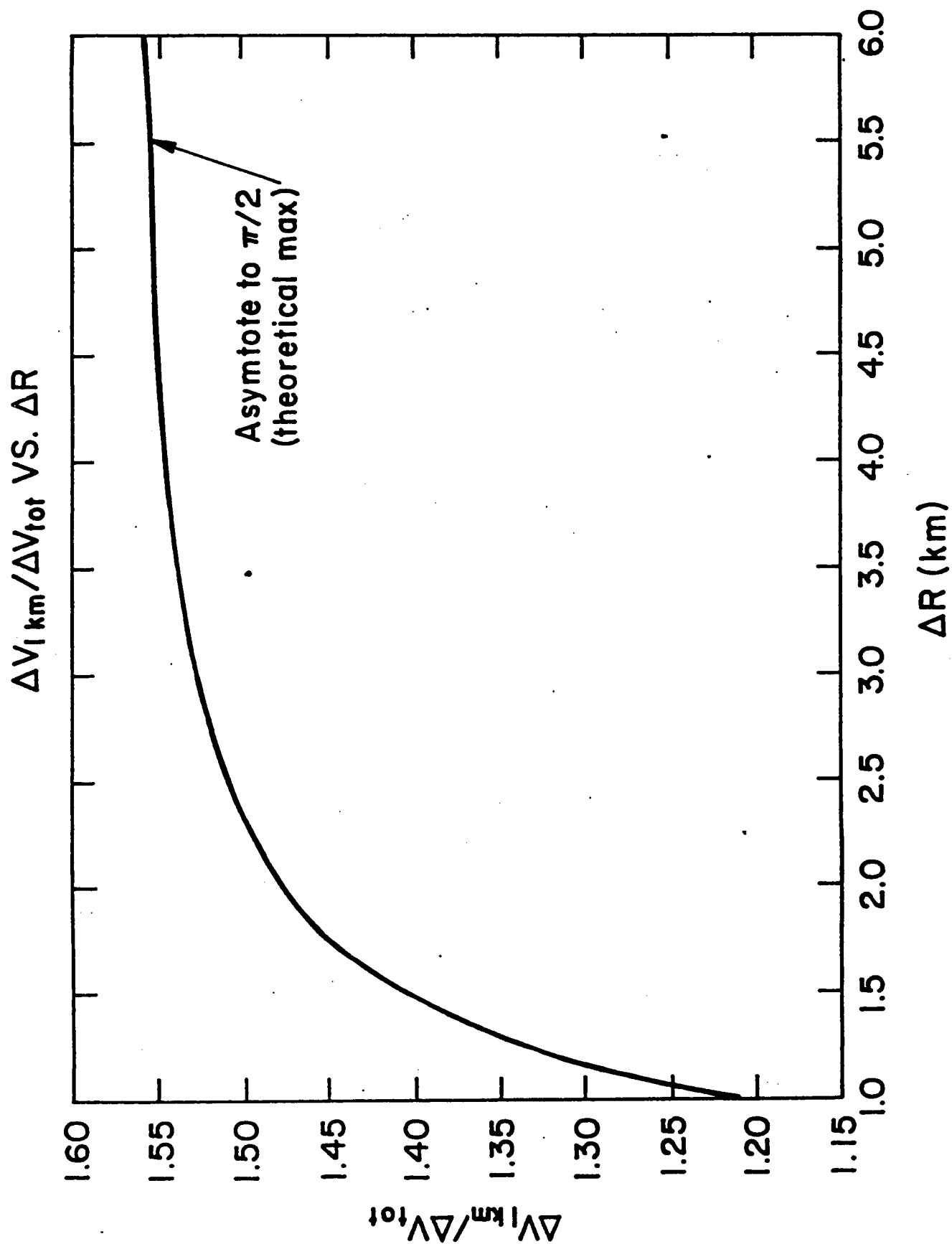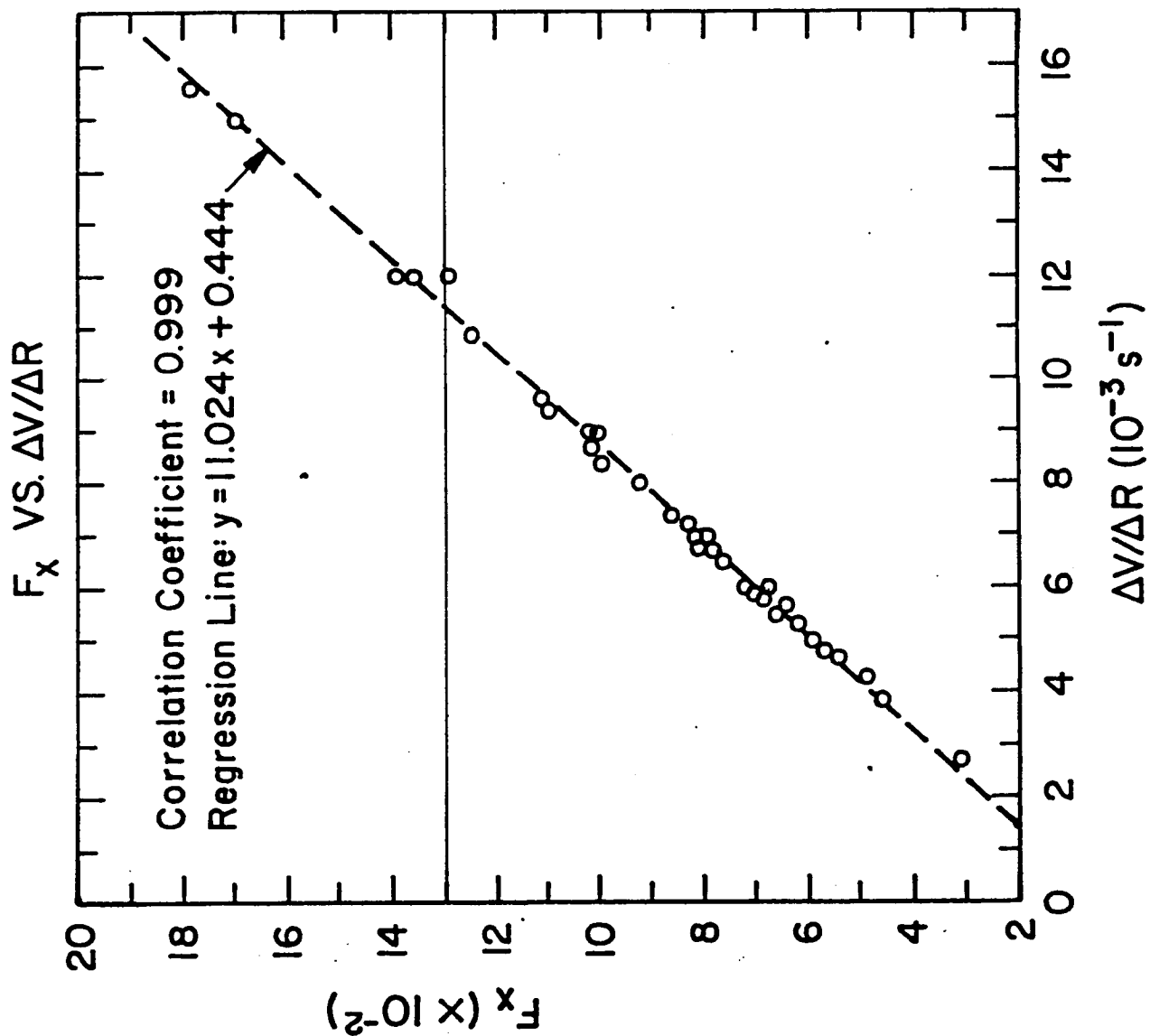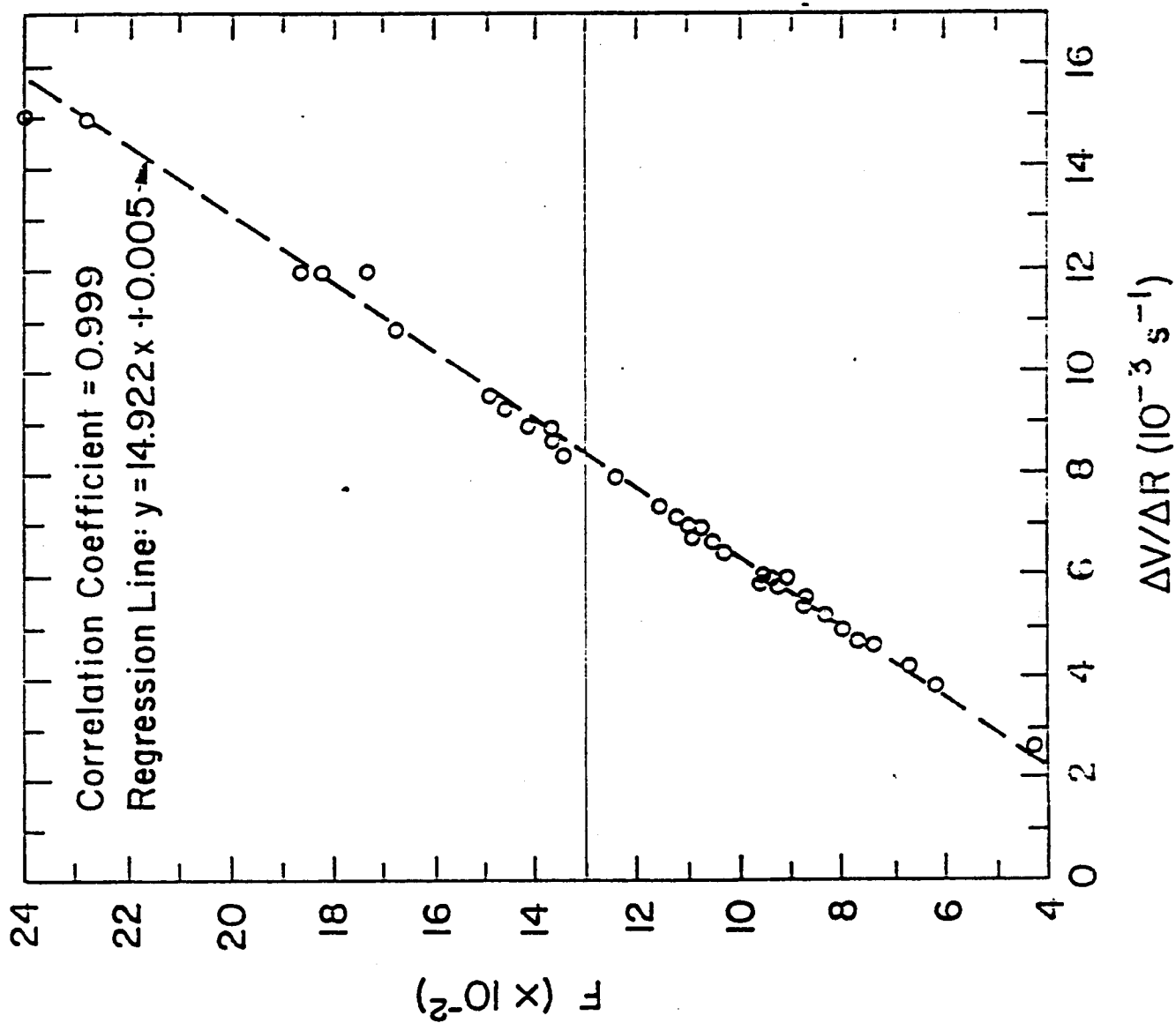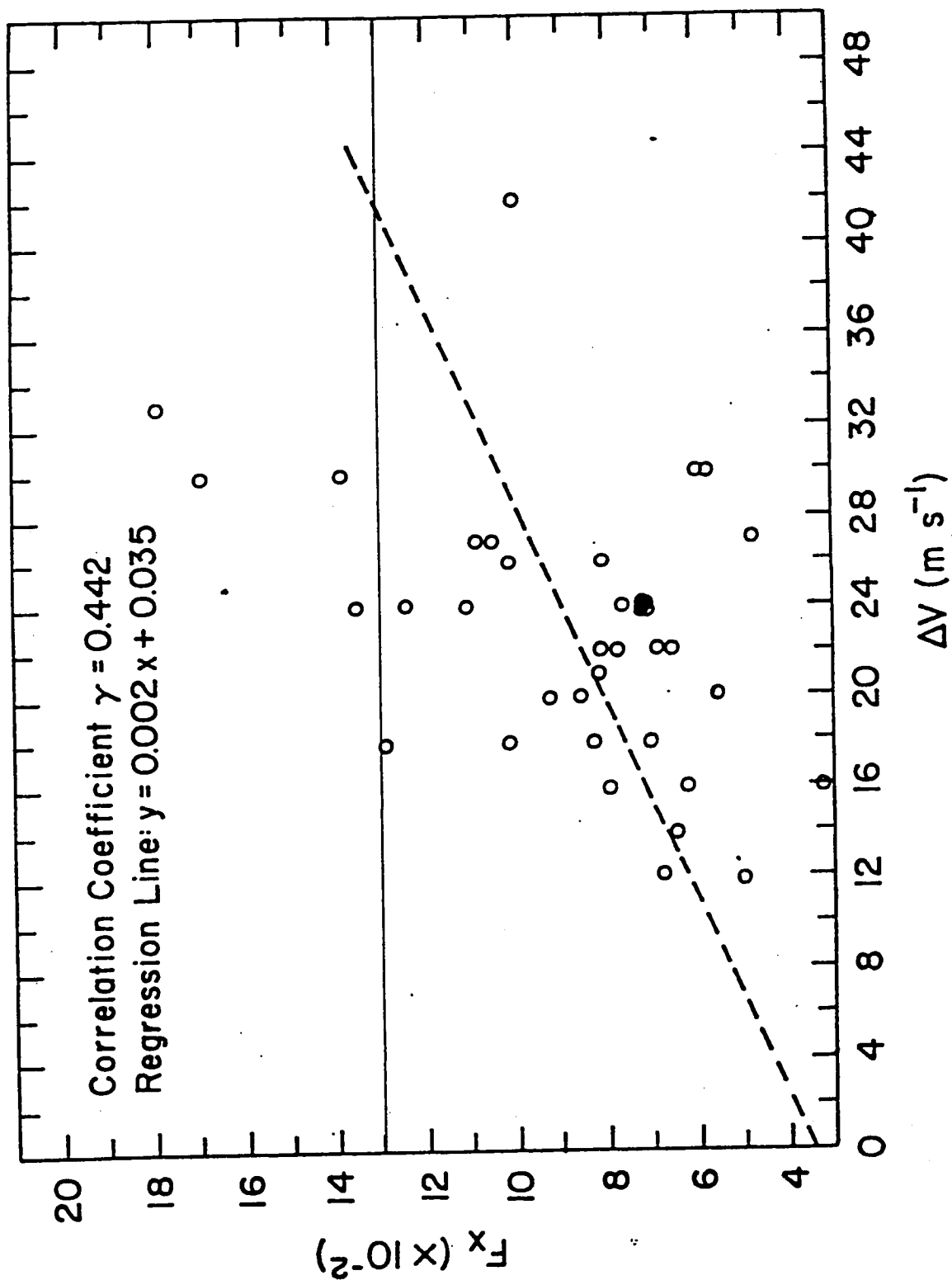
Concluding Remarks

1. The extremely high correlation coefficients that are obtained when F or F_x is regressed onto $\Delta V/\Delta r$ show that the modeled F-factor and the peak-to-peak divergence are equivalent hazard indices that have different thresholds.

2. Use of ΔV alone without reference to a length scale severely limits the potential information content relative to the direct effect of microburst wind shear on aircraft performance.

3. Use of this model links ΔV values to some scale length.

4. Importance of actual shear distribution and velocity profile is still unknown. Simple ΔV estimats of 15 kts have been shown to cause aircraft accidents; scaled to 1 nmi, this is only about 50% of the F-factor thought to pose a hazard.

5. $\vec{w}$ appears to be a significant contribution to the total hazard.

Session I. Ground Systems

Summer 1988 TDWR Microburst Analysis
Mark W. Merritt, MIT Lincoln Laboratory

SUMMER 1988 TDWR MICROBURST ANALYSIS*

Mark W. Merritt
MIT Lincoln Laboratory
Lexington, MA 02173

ABSTRACT

The Terminal Doppler Weather Radar (TDWR) testbed system was operated during the months of July–August 1988 in a live operational demonstration providing microburst (and related weather hazard) protection to the Stapleton International Airport in Denver, CO. During this time period, the performance of the detection system was carefully monitored in an effort to determine the reliability of the system. Initial performance analysis indicates that the microburst detection component of TDWR satisfies the basic performance goals of 90% probability of detection and 10% probability of false alarm.

An in-depth study of the system performance, based on analysis of both dual-Doppler radar observations and surface mesonet measurements, is in progress to provide a detailed understanding of the observability of microbursts by the radar, the ability of the algorithms to detect microbursts observed by the radar, and the timeliness and accuracy of the microburst alarms provided to operational users.

SUMMER 1988 TDWR MICROBURST ANALYSIS

M.W. MERRITT

MIT LINCOLN LABORATORY

- TDWR OPERATIONAL EVALUATION

- "QUICK–LOOK" PERFORMANCE RESULTS

- ANALYSES IN PROGRESS

12 Oct 88

MICROBURST FEATURES ALOFT

Storm Cell

Reflectivity Core
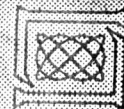
Convergence

Rotation

Downdraft

Divergence

10 km

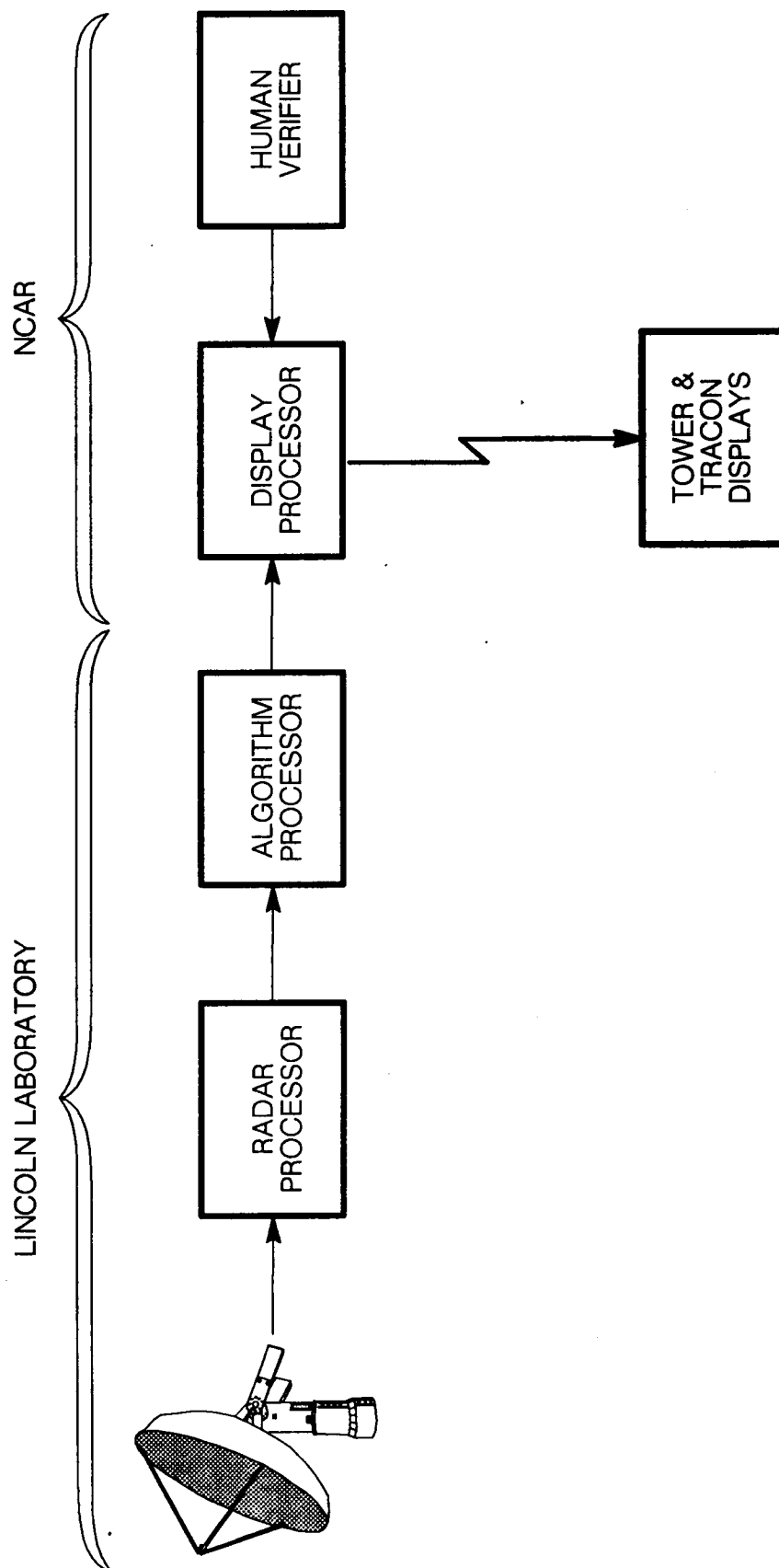5 km

Surface

Upper-level Precursor
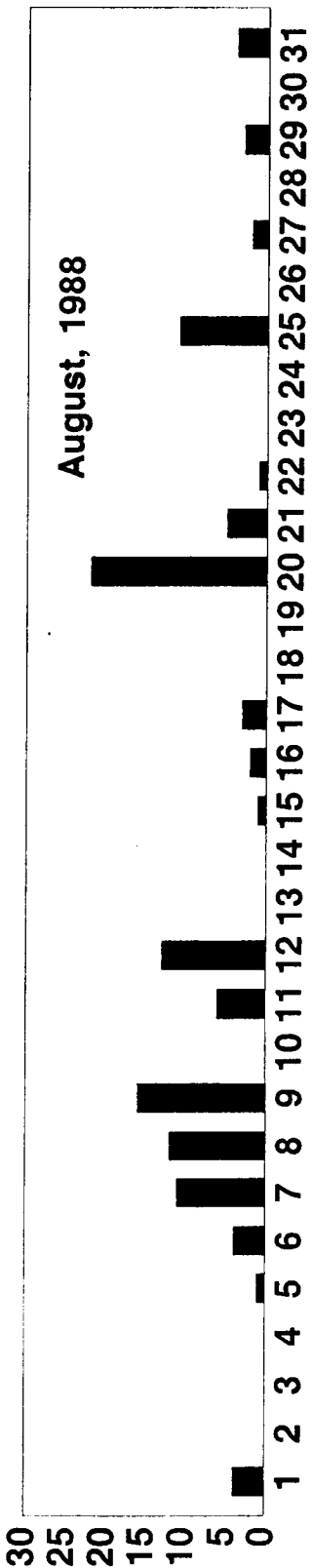(above 2.5 km)

Middle-level Precursor
(1.0 - 2.5 km)

Surface Microburst

743

42-2301

TDWR DEMONSTRATION SYSTEM

744

SUMMARY OF MICROBURST EVENTS

Number of microbursts per day (from daily logs)

July, 1988

August, 1988

12 Oct 88

745
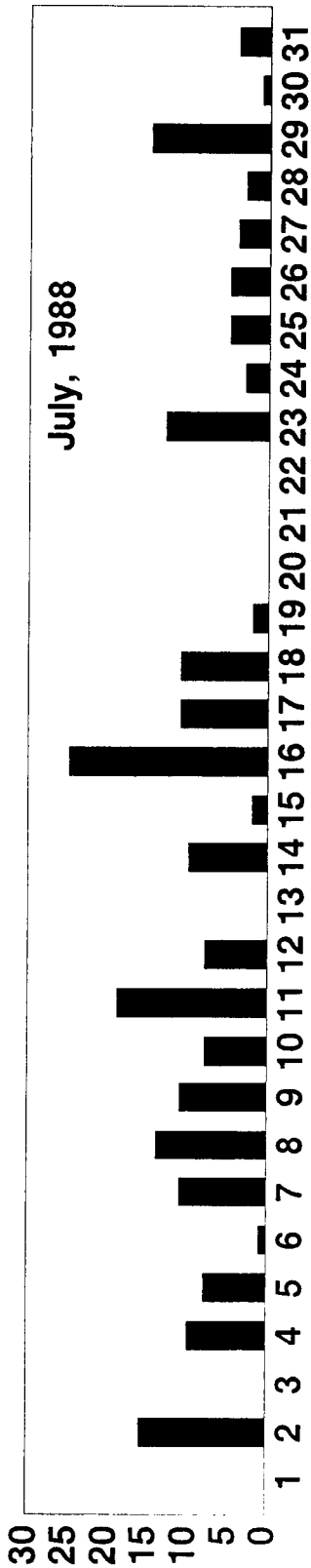
FAA GOALS FOR TDWR
MICROBURST DETECTION PERFORMANCE

- \> 90% PROBABILITY OF DETECTION

- \< 10% PROBABILITY OF FALSE ALARM

- ONE MINUTE ADVANCE WARNING

- +/– 5 KNOTS (OR 20%) ACCURACY ON STRENGTH

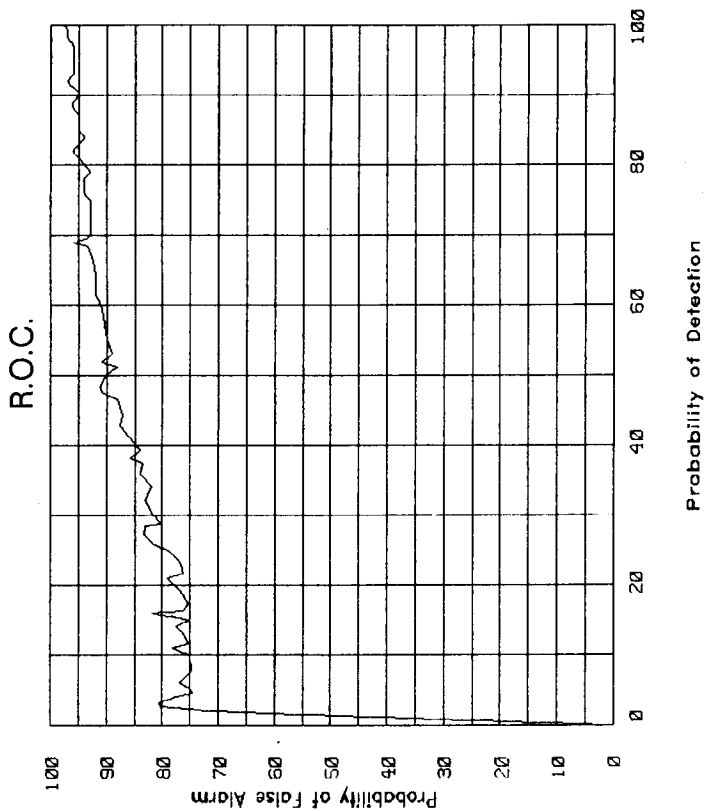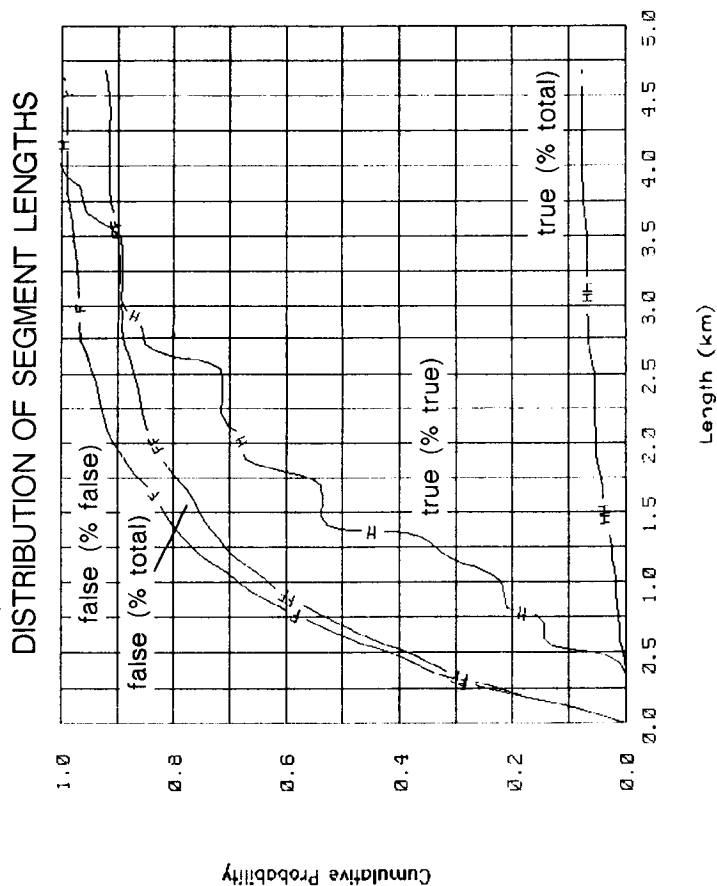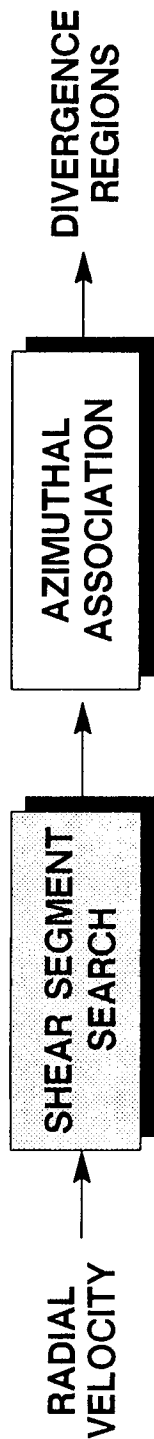# ALGORITHM SCORING PROCEDURE

747
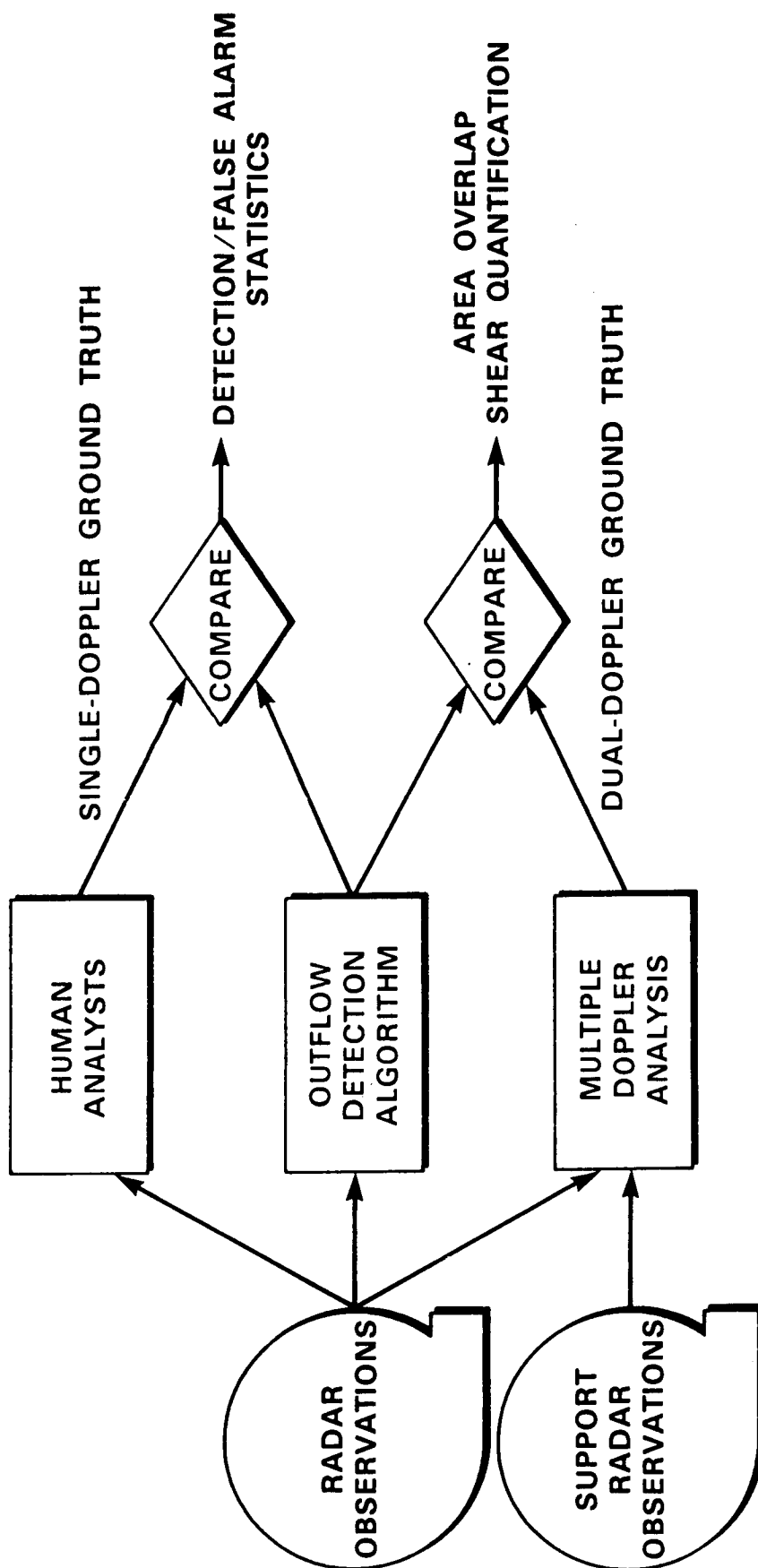
MICROBURST PERFORMANCE ANALYSIS
(SINGLE DOPPLER GROUND TRUTH)

Date	TRUE EVENTS		Detected Events	
	>15 m/s	≤15 m/s	>15 m/s	≤15 m/s
10 June 88	59	37	56	28
21 June 88	45	36	44	32
25 June 88	70	19	69	16
7 July 88	46	48	43	32
17 July 88	39	1	38	1
Totals	259	141	250	109

Probability of Detection (>15 m/s) = 250/259 = 97%
Probability of Detection (≤15 m/s) = 109/141 = 77%
Probability of Detection (overall) = 359/400 = 90%
Probability of False Alarm = 21/417 = 5%

748

PERFORMANCE OF
1-DIMENSIONAL SHEAR LOCATION ALGORITHM

RADIAL
VELOCITY → SHEAR SEGMENT
SEARCH → AZIMUTHAL
ASSOCIATION → DIVERGENCE
REGIONS

R.O.C.

DISTRIBUTION OF SEGMENT LENGTHS

12 Oct 88

749

TIMELINESS OF MICROBURST DETECTIONS

HOW MUCH ADVANCE WARNING CAN BE PROVIDED TO PILOTS BY A GROUND–BASED RADAR SYSTEM?

DATE	SURFACE ONLY	3–D ALGORITHM	IMPROVEMENT	PRECURSOR WARNING
7 JUNE 1986	0.0	+1.3	+1.3	+10.1
25 JULY 1986	–1.8	–0.8	+1.0	+6.0
31 JULY 1986	–0.9	0.0	+0.9	+5.7
23 MAY 1987(a)	–3.4	–2.5	+0.9	+6.3
23 MAY 1987(b)	0.0	+2.6	+2.6	+4.7
23 MAY 1987(c)	0.0	0.0	0.0	+4.8
23 MAY 1987(d)	0.0	+2.3	+2.3	+5.9
AVERAGE	–0.9	+0.4	+1.3	+6.2

(MINUTES PRECEEDING START OF EVENT)

RADAR OBSERVABILITY OF MICROBURST OUTFLOWS

DENVER, 1988

- COMPARE RADAR OBSERVATIONS WITH SURFACE MESONET

- TIME PERIOD: 1 JULY – 31 AUGUST 1988

- SUMMARY RESULTS:

RADAR

	HIT	MISS
MESONET HIT	66 (94.3%)	2 (2.9%)
MESONET MISS	2 (2.9%)	?

Session I. Ground Systems

Automatic Detection of Low Altitude Wind Shear Due to Gust Fronts in the Terminal Doppler Weather Radar Operational Demonstration
Diana Klingle-Wilson, MIT Lincoln Laboratory

Automatic Detection of Low Altitude Wind Shear Due to Gust Fronts in the Terminal Doppler Weather Radar Operational Demonstration*

Diana Klingle-Wilson
Massachusetts Institute of Technology Lincoln Laboratory
Lexington, MA 02173

ABSTRACT

A gust front is the leading edge of the cold air outflow from a thunderstorm. Wind shears and turbulence along the gust front may produce potentially hazardous conditions for an aircraft on takeoff or landing such that runway operations are significantly impacted. The Federal Aviation Administration (FAA) has therefore determined that the detection of gust fronts in the terminal environment be an integral part of the Terminal Doppler Weather Radar (TDWR) system. Detection of these shears by the Gust Front Algorithm permits the generation of warnings that can be issued to pilots on approach and departure. In addition to the detection capability, the algorithm provides an estimate of the wind speed and direction following the gust front (termed wind shift) and the forecasted location of the gust front up to 20 minutes before it impacts terminal operations. This has shown utility as a runway management tool, alerting runway supervisors to approaching wind shifts and the possible need to change runway configurations.

The formation and characteristics of gust fronts and their signatures in Doppler radar data will be discussed. A brief description of the algorithm and its products for use by Air Traffic Control (ATC), along with an assessment of the algorithm's performance during the 1988 Operational Test and Evaluation, will be presented.

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AUTOMATIC DETECTION OF LOW ALTITUDE WIND SHEAR DUE TO GUST FRONTS IN THE TERMINAL DOPPLER WEATHER RADAR OPERATIONAL DEMONSTRATION

DIANA KLINGLE-WILSON

OVERVIEW

- FORMATION AND CHARACTER OF GUST FRONTS

- GUST FRONTS AS AN AVIATION HAZARD

- GUST FRONT SIGNATURES IN DOPPLER RADAR DATA

- GUST FRONT ALGORITHM AND PRODUCTS FOR ATC

- GROUND TRUTH AND SCORING

- RESULTS FROM 1988 TDWR OT&E

- ONGOING WORK

- CONCLUSIONS

109217-5

FORMATION AND CHARACTERISTICS

A gust front is the leading edge of the cold air outflow generated when the downdraft from a thunderstorm reaches the ground and spreads horizontally. The outflow can propagate many kilometers from the parent storm and may continue to exist after the parent storm has dissipated. The passage of a gust front is identified by a sharp drop in temperature and strong gusty winds (from which the name "gust front" is derived).

AVIATION HAZARDS

Because gust fronts can move far from the parent storm, there may be no visual clues to a pilot that a gust front is in the vicinity. An aircraft that encounters a gust front during takeoff or landing typically experiences a gain in the headwind. This may cause a landing aircraft to land long. Hazardous turbulence and downdrafts have also been reported in association with gust fronts

The wind shifts that accompany gust fronts can disrupt airport operations by necessitating the reconfiguration of runways, resulting in costly delays. Advanced warning of a gust front can be used for planning purposes.
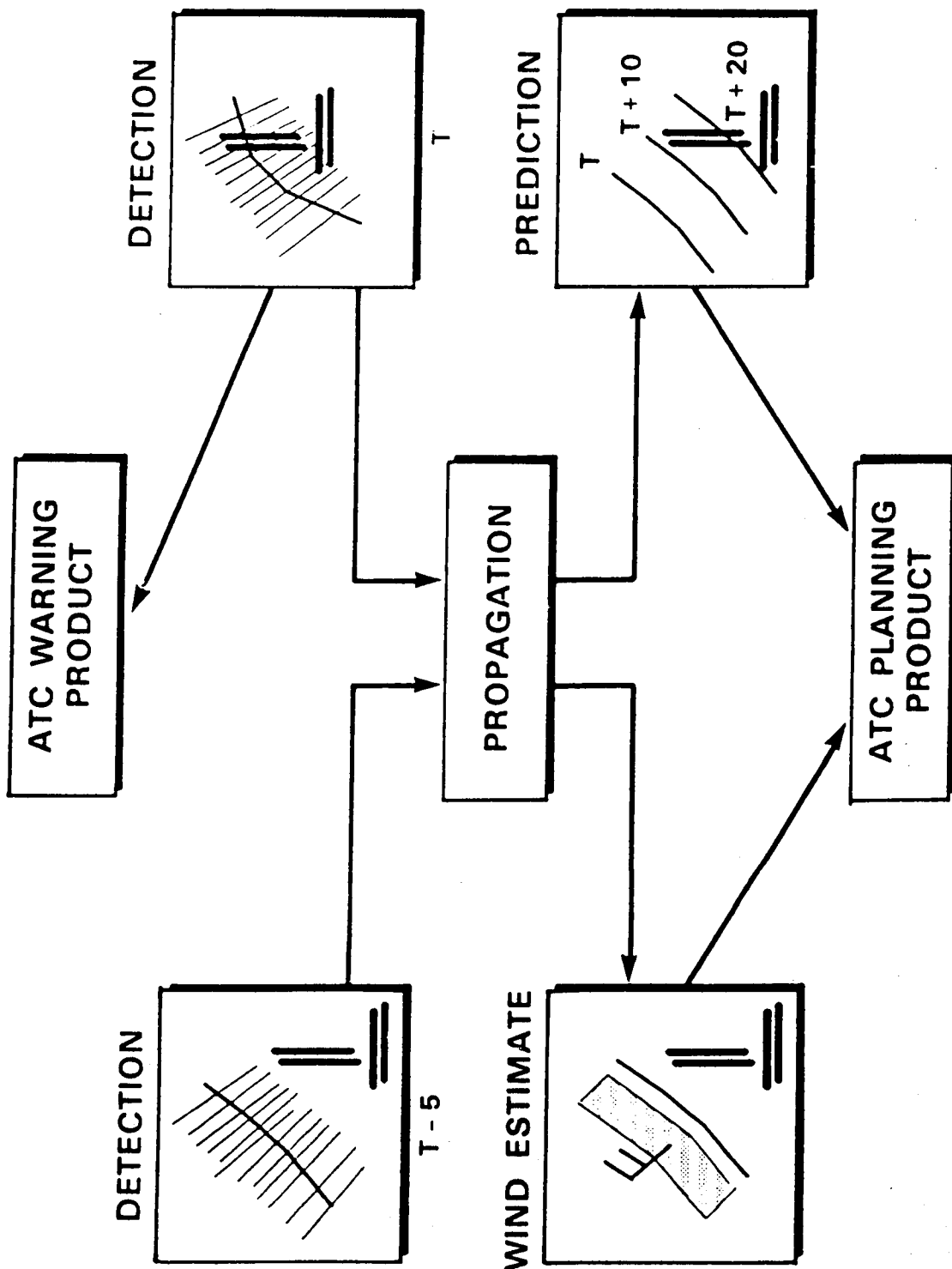
GUST FRONT/WIND SHIFT
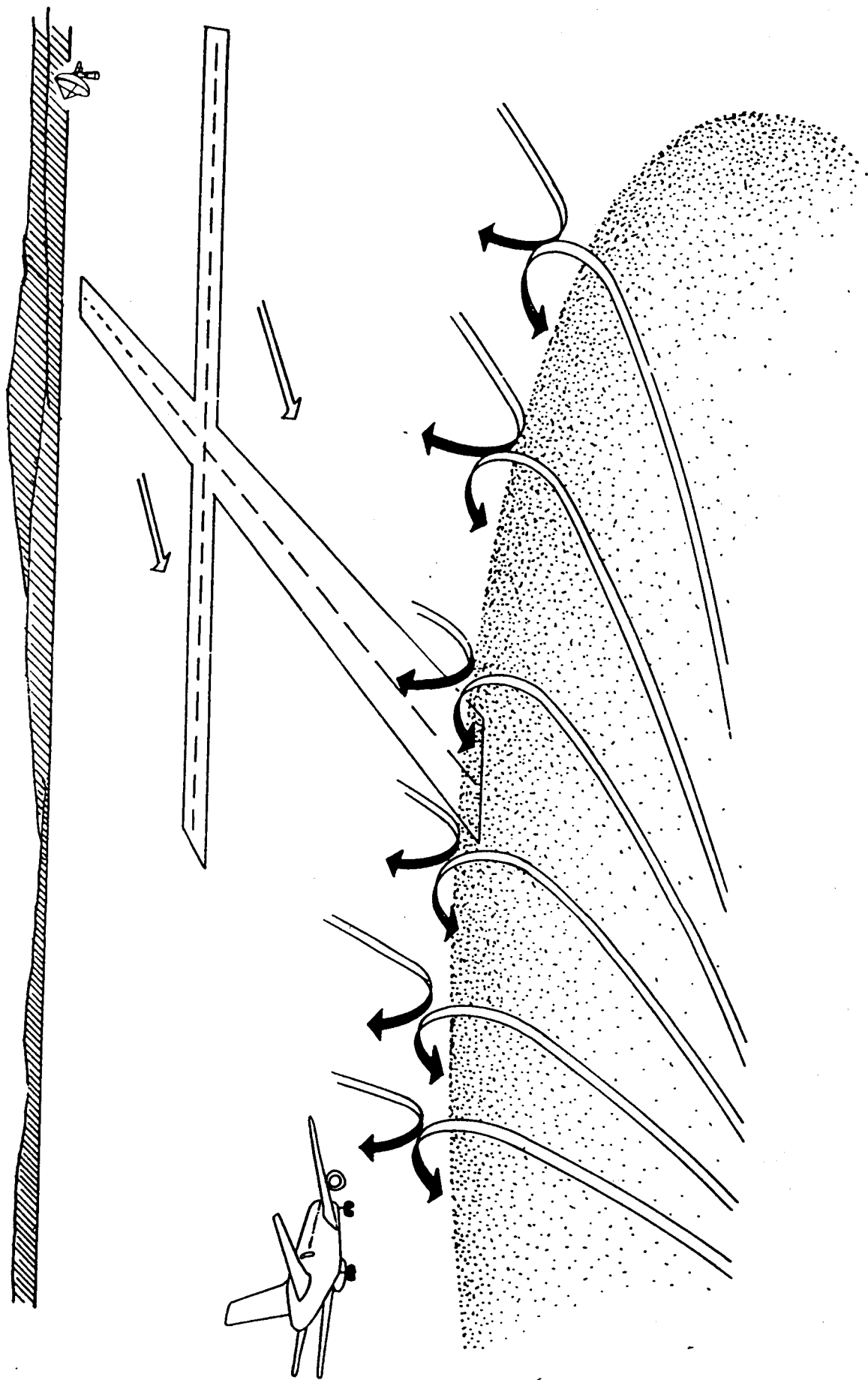
GUST FRONT ALGORITHM AND ATC PRODUCTS

In simplified terms, the Gust Front Algorithm searches along radials for segments of converging radial velocities. These segments are associated, based upon spatial proximity, into gust fronts. If a gust front impacts the runways (time T), the mean and standard deviation of the peak shears along all associated segments are computed and summed to determine the wind shear value encoded into the warnings issued by the Air Traffic Controllers to pilots.

Once a gust front is detected on two consecutive scans (at time T−5 and T), its propagation speed and direction are computed. From this it is possible to forecast the location of the gust front at 10 and 20 minutes. An estimate of the wind speed and direction behind the gust front is computed. This information is passed to the Air Traffic Control Supervisor who determines if runway reconfiguration is necessary.

DETECTION

T

PREDICTION

T

T + 10

T + 20

ATC WARNING
PRODUCT

PROPAGATION

ATC PLANNING
PRODUCT

DETECTION

T – 5

WIND ESTIMATE

GEOGRAPHIC SITUATION DISPLAY (GSD)

This is an example of the display of the algorithm products presented to Air Traffic Control Supervisors at Stapleton International Airport on 11 July 1988. The detected position of the gust front is given by a solid purple line and 10 and 20 minute forecasts positions by dashed lines. The estimated direction of the wind behing the gust front is indicated by an arrow and wind speed by a numerical value. The red circles are microbursts. The proximity of the gust front to the runways causes a wind shear alert message to be issued to Air Traffic Controllers, which is then passed to pilots. Here, microburst alerts override gust front alerts on the east–west runways, but gust front alerts are issued for the north–south runways.
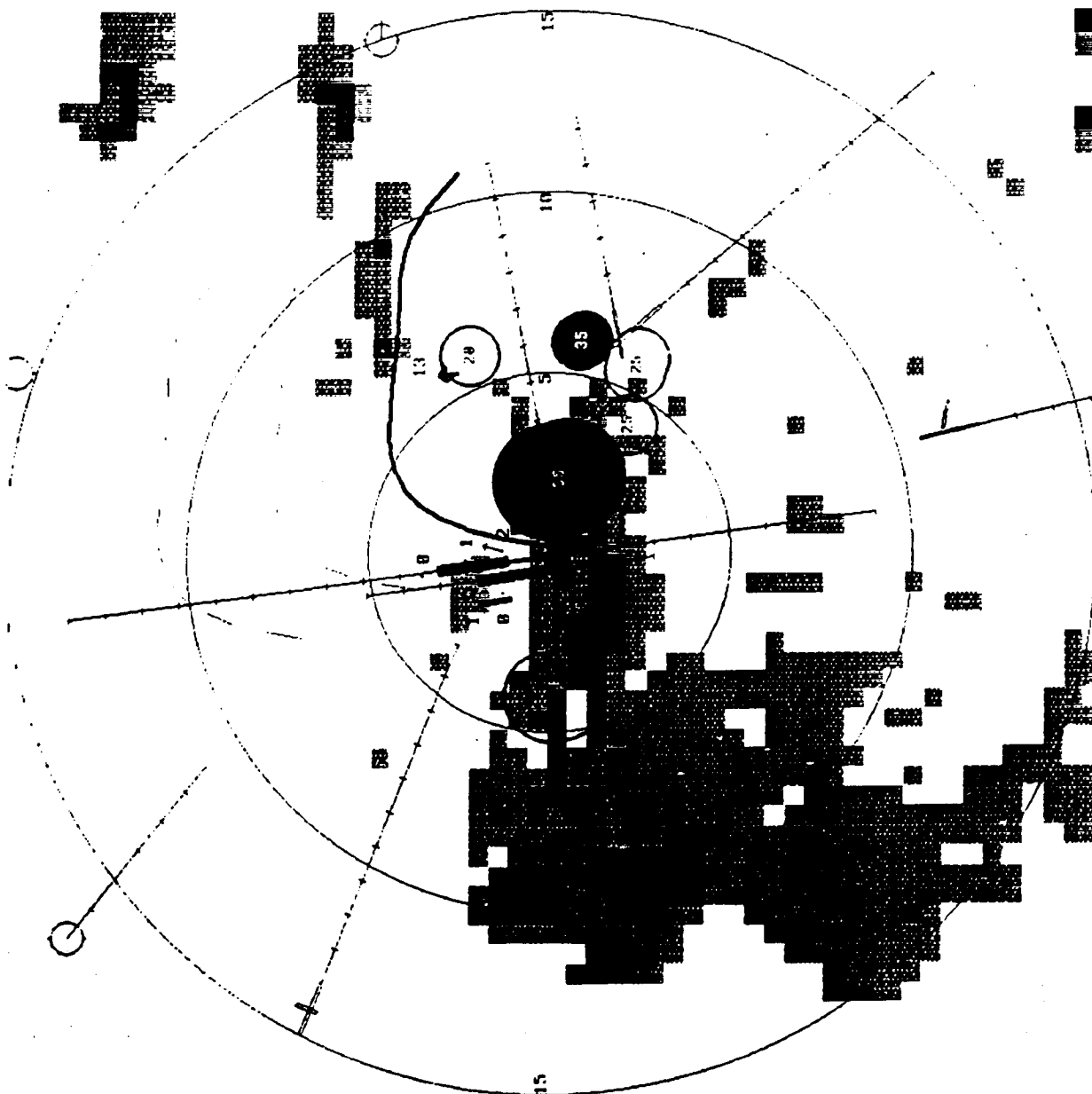
SUPPORT SOFTWARE

The performance assessment of the Gust Front Algorithm is assisted by software that allow the generation and archival of ground truth and algorithm outputs in real-time and automated scoring offline.

In real-time, radar data are passed to the Gust Front Algorithm for processing. Algorithm outputs are written to an archive file and, along with the raw data, are displayed on a Sun workstation. A weather expert enters into a ground truth data file the strength and location of all gust fronts. This file is converted offline into an archive file.

The ground truth and algorithm archive files are merged into a database. These data are then passed through software that automatically computes the probability of detection and probability of false alarm.

GUST FRONT SUPPORT SOFTWARE
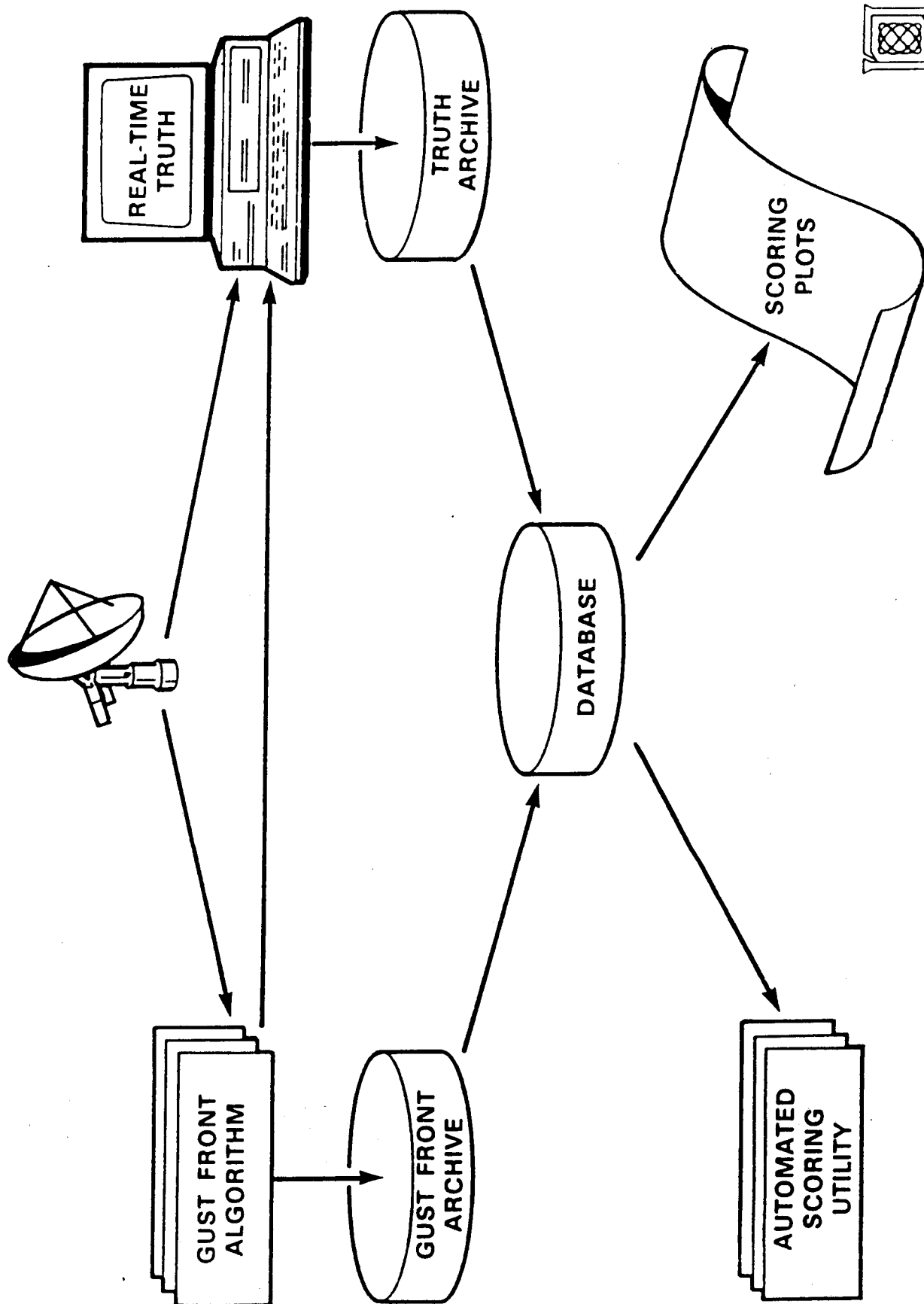
RESULTS

Results of the performance assessment of the Gust Front Algorithm are shown here. POD is Probability of Detection, PFA is Probability of False Alarm. For hazard warnings, these statistics refer to gust fronts that occurred in the vicinity of the airport. For the planning function, POD and PFA refer to all gust front within 60 km of the radar.

PCF is the Probability of Correct Forecast and PFF is the Probability of False Forecast. A correct forecast is one that falls within the truth box at the time for which the forecast is valid. If the gust front dissipates before the forecast is valid, a false forecast is declared. Although the PCF for the forecasts is high, forecasts were issued for only 45% of the 270 gust fronts that occurred during the analysis period.

Ground truth for the wind shift estimate is derived from mesonet data. Thus only wind shifts for those gust fronts that passed through the mesonet (*i.e.*, over the airport) are scored.

Air Traffic Control Supervisors were asked to assess the usefulness of the planning function for the Gust Front Algorithm. Their responses are shown here.
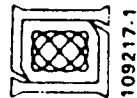
RESULTS

HAZARD WARNINGS

- POD = 0.70   PFA = 0.02

- WIND SHEAR INTENSITY ERROR = 10 KNOTS

PLANNING FUNCTION

- DETECTION

  - POD = 0.76   PFA = 0.02

- FORECASTING (When Possible)

  - PCF = 0.95   PFF = 0.11 (10 min)

  - PCF = 0.83   PFF = 0.18 (20 min)

- WIND SHIFT ESTIMATE

  - SPEED ERROR = 3 m/s

  - DIRECTION ERROR = 30°

- CONTROLLER ASSESSMENT (7 Supervisors)

  - 3 VERY GOOD, 2 GOOD, 1 FAIRLY GOOD, 1 FAIR

ONGOING WORK

Although the Gust Front Algorithm detected over 75% of the gust fronts, only about 70% of their total length was found (which corresponds to about 85% of the convergent portion of gust fronts). There exists a need to improve the convergence detection. This will result in better warnings and forecasts. One way to accomplish this is to relax the shear thresholds once a detection has been declared to help fill in missing portions.

Tracking of gust front is accomplished by centroid tracking. The position of the centroid is dependent upon the detected length of the gust front. If the percent of the detected length varies greatly from scan to scan, the centroid does not well represent the gust front motion and the gust front can appear to propagate in the wrong direction. A better gust front tracker is needed.

The intensities for the pilot warnings tended to be too large. In addition, pilots often report turbulence in the vicinity of a gust front. Thus, the pilot warnings need to be revised to more closely reflect the hazards that the pilots encounter.

The ability to detect the thin line and azimuthal shears associated with gust fronts will improve detection.

ONGOING WORK

- IMPROVE CONVERGENCE DETECTION

- ADD THIN LINE AND AZIMUTHAL SHEAR DETECTION

- IMPROVE TRACKING/FORECASTING

- IMPROVE PILOT WARNINGS

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CONCLUSIONS

- AUTOMATIC DETECTION OF GUST FRONTS ESSENTIAL FOR TERMINAL SURVEILLANCE

- GUST FRONT ALGORITHM PROVED OPERATIONALLY USEFUL IN HAZARD DETECTION AND PLANNING FUNCTION

- REFINEMENTS AND ENHANCEMENTS UNDERWAY

109217-3

Session II. Perspective

Session II. Perspective

Some Perspective on the Wind Shear Protection Problem
Sam Saint, Safe Flight

SOME PERSPECTIVE ON THE WIND SHEAR PROTECTION PROBLEM

Sam Saint
Aviation Consultant

Second Combined Manufacturers and Technology
Airborne Wind Shear Review Meeting

Sponsored by NASA/FAA

October 18-20, 1988
Fort Magruder
Williamsburg, Virginia

What we have accomplished and what yet remains to be done.

Not everyone yet realizes what a landmark decision FAA made when they went into the Federal Register with a new regulation mandating ONBOARD WIND SHEAR PROTECTION.

The FAA action taken last month was absolutely right. This is clearly the first giant step along the road to total wind shear protection.

We have come a long way.

Unfortunately, however, there is a residue of misunderstanding about the role of the onboard protection now mandated by FAA.

That residue of misunderstanding was put in print in the AP story of FAA's order "to equip all ... planes with devices that will help pilots detect and escape from deadly shifts in the wind." This was the AP story filed on September 22nd, as reported in the NY Times on September 23rd.

Describing the wind shear disaster at Dallas-Fort Worth in August of 1985, the AP story said the newly mandated equipment "tells the pilot when the plane is in the midst of conditions as dangerous as those at Dallas-Fort Worth in 1985." Then comes this sentence: "By that time, critics of the equipment suggest, ... it may already be too late ..."

The last paragraph of the AP story (as it appeared in the NY Times) reads this way:

"Many pilots insist that it is virtually impossible to escape a powerful microburst like the one that struck the Delta plane at Dallas-Fort Worth or the one encountered by a Pan American World Airways jetliner that crashed as it was taking off from New Orleans in 1982."

The AP story is wrong on two counts.

The assertion that a warning when the plane is "in the midst of [the microburst] conditions ... may already be too late," is wrong, as I will show you in moment.

777

And, the AP story, quoting "many pilots", implies that use of the mandated equipment would, maybe, not have saved either the Pan American disaster at New Orleans, or the Delta tragedy at Dallas-Fort Worth.

This is a totally wrong conclusion, as I think many of you here in this room already know.

To put it bluntly, there are still some people who believe the onboard "reactive" systems FAA has now mandated are simply another "band-aid" solution, to give some protection while we wait for the real solution from the ground-based and/or airborne "look-ahead" systems they insist we really want.

We could talk about how these erroneous ideas got started, but this would not be fruitful today. What we really want is a clear answer to each of three questions:

One, will the warning the pilot gets from the currently mandated equipment come too late?

Two, will the warning the pilot gets from the currently mandated equipment give the pilot the capability of escaping from microbursts like that at JFK on June 24th, 1975, like New Orleans on July 9th, 1982, and like Dallas-Fort Worth on August 2nd, 1985? These three worst wind shear disasters since 1975 cost 401 lives and many hundreds of millions of dollars in liability claims. Would the protection now ordered by FAA have saved those lives and kept those three airlines out of the courts?

The third question is this: Will the currently mandated onboard, "reactive" systems become obsolete if and when a "look-ahead" system is perfected?

I first heard what I believe to be the correct answer to this third question from Roland Bowles in the hallway at 800 Independence Avenue during a coffee break. Before I talk about this third question, though, let me give you a solid answer to the first two questions.

Let me answer both of these question with one concrete argument. The currently mandated warning will not come too late, and the mandated equipment, including recovery guidance, would, beyond question, have kept EA-66, PAA-759, and DL-191 out of those smoking headlines.

Give me a moment to back that statement up.

First I need to point out that calling this currently mandated equipment a "reactive" system is an unfortunate choice of words. The so called "reactive" systems will give the pilot an absolute determination that the outside environment is doing something that is outside the limits of normal turbulence. And this warning will be given many critically important seconds before the pilot can judge the situation from his normal instrumentation. Perhaps the most important of all, the spoken words (Wind Shear! Wind Shear! Wind Shear!) from the cockpit loudspeaker, going into the Cockpit Voice Recorder, will take peer pressure off the pilot's back. He can act, without hesitation, well before "it is too late."

A closer look at the accident record will make this clear. Let me give some examples:

EA-66 at JFK on June 24th, 1975 -

The initial warning (based on energy gain) would have come 20 seconds before these pilots realized what was happening. The warning would have come on the basis of a suddenly increasing headwind, with the airplane 420 feet above the ground, ballooning above the glide path, with a headwind of 17 knots and an updraft of 300 feet per minute.

Full power, plus commanded pitch guidance for escape, at that point on the approach would certainly, beyond any question, have kept that aircraft out of the approach lights.

What actually happened was disastrously different. The Captain did not call for go-around power until two seconds before impact.

Without the mandated protection, I believe this could have happened to any pilot. It could have happened to me. The pilot needs the help we are now going to give him.

The mandated warning would have been a "prediction" of the potential danger that lay ahead. I say again, "reactive" is a misleading word.

Continental-426, a takeoff at Denver on
August 7th, 1975 -

This pilot would have been warned when 22 seconds into
his takeoff roll, with a ground speed at that moment of 70
knots. The warning would have come on the basis of an
increasing headwind shear of 7 knots per second, while he
still had more than 8000 feet to get stopped.

Allegheny-121, an attempted go-around at
Philadelphia on June 23rd, 1976 -

Again, on the basis of a sharply increasing headwind,
this pilot would have been warned and would have started his
go-around while still 270 feet in the air, looking at an
airspeed of 160 knots. With the recovery guidance system to
prevent the disastrous, near zero angle of attack at the
critical part of the escape maneuver, there is just no way
this aircraft would have made a 10-G crash landing in the
middle of the airport.

Continental-63, a takeoff at Tucson on
June 23rd, 1977 -

This aircraft ran through utility poles and wires 710
feet beyond the end of the runway.

For Continental Flight 63, the computed warning would
have come from the cockpit loudspeaker 26 seconds into the
takeoff roll. The groundspeed at that moment was 90 knots.
There was approximately 4500 feet of runway left in which to
stop.

No problem.

Pan American-759, a takeoff at New Orleans
on July 9th, 1982 -

In this case, the warning would have come right at lift
off. Thanks to Dr. Fujita's comprehensive analysis of this
record, we can determine that full power, plus commanded pitch
guidance, would have seen this aircraft cross the tree line
that brought it down with a margin of 130 feet.

UAL-633, a takeoff at Denver on May 3rd, 1984 -

This takeoff hit the ILS antenna 1074 feet beyond the end of the runway. There is no way you can come closer to total disaster and keep on going.

These pilots would have been warned in time to have coasted to a stop. A hairy near miss would have been turned into a relaxed operation.

Delta-191 at DFW on August 2nd, 1985 -

The implication that this disastrous accident could not have been prevented by the currently mandated wind shear protection is wide of the mark. Not by any stretch of imagination can this implication have any validity.

The Flight Data Recorder on this aircraft was recording 42 parameters every second. Dr. Ted Fujita's total analysis of this accident is available between hard covers. I have flown a near duplication of this microburst four times in simulation.

For those Delta pilots, the initial warning would have come 18 long seconds before they knew the desperate trouble that lay ahead. This initial warning (based on energy gain) would have come 35 seconds before initial impact, while the aircraft was still 770 feet above the ground, with an airspeed at that moment of 173 knots.

With full power at that point, gear up, and go-around flaps, there is just no way that Ed Conners and his big flying machine could have wound up in a smoking heap on millions of TV tubes.

Let me add a personal word here -

I was an airline pilot for 33 years. If I had been in command of that L-1011 at DFW -- an aircraft that did not have the protective technology we now know how to provide -- it is highly likely that I too would have wound up in that great fireball against those water tanks.

There is a point we need to clear up with
the aviation community -

Gentlemen, with the prestige of this meeting, with the
prestige of the NASA/FAA Team, we need to tell the world that
the mandated, onboard wind shear protection systems should not
be called "reactive" systems. This word still speaks to some
people of a warning that is "too late".

Again and again, it is seen in the accident record that
these new systems will give pilots enough lead time to change
a potential disaster into a safe escape.

We should tell the aviation community that this currently
mandated equipment is not a "band-aid" solution. We are not
talking about a "crash alarm", as some have suggested. We are
talking about a solid solution of a difficult and very complex
problem.

That leads us to the third question we
asked earlier -

Will the currently mandated equipment become obsolete if
and when the "look-ahead" (Doppler, laser, Lidar, infrared --
airborne or ground-based) systems become available?

Careful examination makes it clear that Roland Bowles at
NASA and Herb Schlickenmaier at FAA have been right all along.
Roland was the first to say this in my hearing: The
"reactive" systems already flying with FAA certification will
not be throw-away technology.

We need to say, with the considerable force of these
important, NASA/FAA sponsored meetings -- we need to tell the
aviation community that the currently mandated equipment forms
a solid foundation to which additional improvements should be
made as they come along.

Now, a word about what yet remains to be done -

Four of the eight accidents in the NTSB records, from
EA-66 in 1975 to DL-191 in 1985, were takeoff accidents.

Clearly, we need protection from a microburst encounter
during the takeoff roll. But there is a problem that has not
yet been resolved.

At least one major airframe manufacturer and two major airlines have argued that a wind shear warning system must be deactivated during the critical phase of a takeoff. The fear is, of course, that an aborted takeoff could be triggered that might turn into a disaster. The threat of liability looms like a specter in the background.

I can understand this fear. It is a valid concern. Two engineering pilots, whose judgment I regard very highly, have told me that we need to resolve the total runway monitoring problem before we can allow the wind shear warning system to be enabled during the most critical part of the takeoff roll.

I agree that this is an unsolved problem that still lies ahead. Complete runway monitoring will involve many factors other than a possible microburst encounter. With today's technology, however, I believe we can solve the runway monitoring problem.

Let me put my Safe Flight hat on for one final minute –

I want to say I am proud to be a member of the Safe Flight Instrument Corporation team.

Safe Flight was years ahead of everyone else in arriving at the correct basic concept for a warning system. Safe Flight was first to understand that the horizontal and vertical winds at the outer edge of a microburst should be measured to provide the earliest possible look at the "footprint" -- the "signature" -- of the hazard that lies ahead.

Seven years ago, when I was catapulted into this problem, Safe Flight stood alone in having a clear understanding of what we now know to be the way the threat should be measured. There were many other approaches being pursued. Today, there is a strong consensus that the basic concept pioneered by Safe Flight is the correct approach to an onboard warning system. And this basic concept meets the requirements of FAA's new rule.

Safe Flight was the first to seriously argue that the pilot needs computed recovery guidance, and to provide that guidance.

Safe Flight was the first to argue for wind shear protection during the takeoff roll, and to develop that protection.

All through the years of the jet era, we have known that speed targets provided an inadequate signal for the extremely critical takeoff decision points.

In the course of working toward microburst protection during the takeoff roll, Safe Flight has invented and now offers "Runway Rotation Guidance". This is rotation command based on real world inputs of both ground speed and airspeed.

This, I firmly believe, will eventually replace the totally inadequate speed targets for marking the last safe abort point and the point at which rotation should take place.

Thank you for listening.

Session II. Perspective

Lessons Learned
William Laynor, NTSB

Lessons Learned - William Laynor, NTSB

I'm not real sure what Herb meant when he gave me the title, "Lessons Learned" here. I thought maybe I was supposed to give a test. It's always a pleasure to follow Sam, of course, because I've known Sam for a long time. I'm going to take the opportunity to echo some of the things that he said. I want to really present an overview of the Safety Board's views and progress made to date and some observations on the discussions that I've heard during the last couple of days. But before that I want to mention a probable cause.

About two years ago, out at the SAE Aerospace Technology Conference in Long Beach, I opened the panel on wind shear. I think a lot of the people here were in the audience and I read a probable cause. The probable cause that I read was, "loss of control of the aircraft due to unusually severe turbulence and violent down draft caused by a thunderstorm of unknown and unpredictable intensity." Since I'm following Sam, I'll tell this story. Shortly before or after, I can't recall which, I was preparing this speech, Sam was in my office and I read that probable cause to Sam and I didn't know exactly which accident he would associate it with. Without blinking an eye, Sam said "Oh yea, I remember it was back in 1943 and it was Captain So and So" (I don't know the captain's name but I venture to say he does) and anyhow, it was July 28, 1943, it was an American Airlines DC3 which encountered a thunder storm near Bowling Green, Kentucky, while enroute at low altitude between Louisville and Nashville. The significant part of that accident report (I dug that accident report out in preparation for that speech) was that back in 1943 there was a very accurate description of a microburst. It wasn't called a microburst, but the accident described the constrained high velocity down draft diverging out (that was evident by ground damage) the trees blown, damage to the ground which was fanned out in a wide range and it was very evident that unlike somebody said earlier that people didn't recognize the microburst hazards, they actually did. In fact, there were a couple of

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recommendations that came out of that report and they were that we needed to conduct research from the dynamics of thunderstorms, and the development of accurate methods of forecasting severe developments. Another one was that there had to be further studies of the behavior of airplanes passing through a verticle downdraft and into a tail wind. I think most of the people here know that the NTSB tracks recommendations and the actions being taken to close them out and we grade them as acceptable actions or unacceptable but I think we've approached the point some 45 years later where we can probably close those recommendations out now.

Obviously progress hasn't been steady during that period of time and even though there were some people and Bill Melvin was one, some of the NASA people, George Spectal I think from Huntsville and there's some people from Ames and Captain Brown from TWA, there were papers that were put out certainly during that period, in the 60s and before the early 70s. But in the early 70s the whole wind shear problem started to be recognized by industry and government. Although the Iberia DC10 accident at Boston Logan in 1973 was actually a funnel system wind shear, not something that would normally infringe upon the performance capability of the airplane. It was certainly a wind shear accident and it infringed upon the Captain's interface with the condition he was going through and that prompted a lot of attention within the industry. Eastern 66 that Sam referred to came along in 1975 and that really got people's attention. Ted Fujita and Fernando Carecina among others started coining words like microburst, downburst, and the whole aviation community became very intensely interested in the subject. I think that I can honestly say that we have seen steady progress since 1975 in addressing the problem, although it's certainly been spurty. It's been accelerated in 1982 with the Kenner accident and it accelerated again in 1985 with the Delta Dallas Forth Worth accident. But back in 1975, people recognized that there was a need for a lot of research. There was a need for development of ground based detection equipment, there was a need for the development of airborne detection equipment and there certainly was a need for

training so that brings us up to 13 years later. I'm not intending to be critical that it's taken 13 years, but I think we have to recognize that there's a lot of technological hurdles that had to be overcome and there's still a lot of them that have to be overcome. There are budget priorities that we're contending with, we've got problems other than wind shear. We've got airborne collisions and a whole host of places to spend money. Government procurement is obviously not necessarily completely efficient, I guess I should say, and rule making takes time, so we've made progress. There's no doubt about that and I think the Safety Board views that progress with a lot of encouragement. The progress has been evident.

We've heard a lot about it here the last couple of days. In 1987 when we had the enhanced LLWAS test out at Stapleton that certainly was a vast improvement over what we had seen in LLWAS in the past and we've got to hustle and get that system in more places. I understand now that it is in New Orleans, but it still has time to go. The TDWR tests, we've heard an awful lot of in the last past couple of days and that's been more than encouraging. The NEXRAD terminal and NEXRADS are coming along. They're under contract and under production I guess. The TDWR itself (I don't know if the contract has been let yet) is imminent. So that sure is encouraging. The ASR9; I think perhaps the wind shear community hasn't paid quite as much attention as it should to the implementation of the ASR9 and the features that it's going to bring for places where we don't get the Terminal Doppler and how they integrate it with the LLWAS. I was encouraged this morning when Art Hanson at least touched upon that pretty much. It was kind of encouraging to think that it is being thought about someplace. Flight crew training aides were delivered to the FAA, February 1987, a year and a half ago, almost two years ago. That represented a very intensive effort by the manufacturers in the community. I agree with Sam that the rule making that's just been passed is a landmark rule making because we certainly need that training as well as the reactive, in situ devices that Sam is talking about. The Safety Board supported that rule making very strongly and we supported the

reactive devices and both the detection and the guidance aspects of it. Like we know that in the preamble there was a lot of controversial comments about the need for the guidance, but in our view, so long as you have airplanes flying with speed command, alpha command and flight directors, we have to do something to improve the crew's chances of executing a successful escape manuever and that requires this guidance. The forward looking sensors, the discussions here were very interesting. There's a lot of good technology and we certainly want to see that program move forward. It seems to me that there are still a lot of hurdles that need to be overcome. I certainly disagree that we should have waited until those systems came along before *we went into rule making with the presently available devices. And in fact, I've heard some comments during this discussion from various people here and outside where they've expressed concern that this rule making that's on the presently available devices is going to inhibit development or can potentially inhibit development of the forward looking devices. Why, I certainly hope not. But I thought it was interesting when Howard Long, at some point yesterday, brought up the question of what happens when the down draft, a very intensive downdraft, descends on the airplane rather than the airplane running into it. I think that we've see that in some of the wind shear incidents we've investigated. I'm not sure about the accidents but I do know we've investigated incidents where pilots had clear visibility, had no signs of constrained rain shaft ahead of them and then all of sudden they're deluged in rain and they've got the wind shear effect. So the forward looking sensors may not always do the trick. One is not going to substitute for the other in my view.

I want to make a couple of observations on the discussions during the last few days, Bob Ireland was up here a couple of days ago and was talking about the July 11 incident at Stapleton. That brought about a lot of discussion from the people in the audience about the controller's and the pilot's performance, which it wasn't intended by Bob, I'm sure. But I think it pointed out that there is a lesson to be learned. We have a lot of human factors work to do and I'm not sure that I want to

use the words total in the human factors side but we have a lot of work to do where we get air traffic controllers, pilots and everybody involved and we've been doing this. When we talk about the controllers job, it's always kind of interesting to me that we focus in only on the subject at hand, wind shear in this case. The NTSB on the other hand, we have to focus in on the runway encouraging problems, the operational errors and everything else. We have to recognize, even though we may not always appear to, that the controller has one heck of a work load these days. They're limited in experience, limited from the standpoint that they may be very well trained but it's been basically a rebuild effort since 1981, they're handling more traffic now they ever did before and their primary concern, irrespectable of what this group might think, is to keep those airplanes apart and that's a big job for them. The point I'm trying to make there is that I don't think we're going to reach the day where you can look to a controller to be able to understand the performance problems facing a pilot, his aircraft. I don't think you're going to be able to look to him (even though we'd like to think he'd have better meteorology training than he has) to do a lot of interpretation of weather data. So we're going to have to come with the tools that give him a very objective way in which to make decisions. If we ever put the decision in the tower and the FAA legal people, the people who decide to suspend operations as a result of any of these readings, will do so because there's an objective way of measuring it and there's a no go light there. The controllers subjectivity is not going to be an issue. Obviously, the July 11 incident pointed out the need to do a little more work on the message format but that was the purpose of that operational demonstration program. What we felt was that there was going to have to be more work done and there is a TDWR LLWAS user group that's certainly going to continue with that. Bob was asked the question (somewhat leading question) at the end of his presentation,.. would there have been an accident had there not been a TDWR and the warning devices and I tend to agree with Bob. I hope he's right that there wouldn't have been but I'm not sure that I agree with him that it's necessarily for the

same reason. Those pilots involved were trained, they had been through the simulator, they probably instinctively knew a little bit better how to react than pilots who perhaps had not received the intensive training. But they could also see the ground and in the accidents that Sam's mentioning (the Eastern JFK Pan Am encounter and Delta Dallas, and just about every one of those cases) we felt that the pilot's visibility was just about nil when he entered the rain shaft and he didn't have the altitude awareness. That's one of the things that really bothered me in Bob assessment when he said that one of the pilots he'd talked to hadn't realized that he had gotten so low. We read out the play data recorders from those airplanes and they did get pretty low. The heavy rain effort itself is .. it's certainly interesting. We strongly support Earl Dunham's work. I thought he had an interesting presentation. We have to continue to establish what the stall margins are in heavy rain. We've looked into it in a theoretical sense after the Delta 191 accident in analysis, but we don't know what the rain fall rate for sure was in that. But we did look at .. we had a good enough flight data recorder that we could look at longitude or acceleration and air speed rate and back out some of the wind defects and then look at the theoretical lift coefficients and see whether there were any rain effects. We didn't see the 30%, certainly that Earl was showing here. In fact, we saw very little. Since a lot of the discussion here concerned views on the compatibility of the ground based systems and the airborne systems (Wayne Sands brought that up this morning) I frankly, personally, believe that it's a worthy objective to get those systems compatible. But I'm probably not as much worried as I've heard some other people indicate *that they have to be perfectly compatible. I think that these events will be rare enough that the pilots have to be trained now, irrespectable of which one gives the warning, he's going to hate it and there certainly are times when you're going to be warned from a ground based system. You won't see it on an airborne system or look ahead airborne system or even an in situ system so I don't think it's really achievable that you're going to get complete compatibility. But that has to be covered by training. Ultimately, I suspect that we

ought to be looking at a way for the data link to get the systems talking to each other so there's really no need for compatibility. A pilot sees a warning and regardless of whether it comes from the ground based system or the airborne system, he's trained to do something about it. I hear people talk about using the F factor hazard index and it's certainly a part of the algorithm to go into any of these systems as detection modes. I certainly don't agree with that there's any need to give the pilot an F factor hazard index. He's got enough to think about when he's just coming in and trying to relate the level. In fact, we take the view that where anything says there's a microburst, it's "get out", don't evaluate whether your airplane has performance to try to penetrate it. Pat Cline was mentioning the false and nuisance alarms after the presentation by Terry Zwiefiel. I'm certainly hopeful that those problems, if there are any, can be solved. I thought the data that was put up by Terry where there one alarm in, I think, 20,000 plus flights, certainly indicated a rarity of the events to the point that nuisance alarms is not going to be all that critical, but there were a lot of analogies made to the GPWS. The GPWS was put into service and those people who say it was put into service prematurely, from the Safety Board's standpoint, we will argue against that violently, because it undoubtedly started preventing accidents as soon as it went into service. The evolution of the performance of those systems, you very seldom hear complaints these days. Some of these guys might take issue with that, but that's my view.

Again, I've heard discussion that the rule for the reactive devices will inhibit industry's development of the look ahead system. I certainly hope not. I think that industry has to continue to strive just like they do from going from black and white to color radar and the turbulence modes on radar. There are going to be constant improvements in the systems and all the technologies being discussed here have to be given a chance. But the systems have to complement each other to the extent that the reactive systems and the guidance should complement the onboard look ahead systems. It brings me to where we are and what's still needed. I think Wayne did

a pretty good wrap up of what's still needed today. We generally concur with him. The enhanced LLWAS -- there has to be work there. We're strong advocates of getting sensors out on the approach and departure path because even with the expanded array within the airport boundary, we're going to miss some critical events that could cause accidents and I think that's well recognized in the FAA and like Craig said, it's a budget and resource problem. I'm sure there's going to be a day, probably pretty soon, when we're going to look at priorities and whether systems have to be enhanced and it's going to be weighed whether there's a TDWR there or whether there isn't, whether there's an ASR9 and a lot can be done, probably, to combine the ASR9 and LLWAS (without a TDWR to improve the situation where the TDWR is not going to be installed) I was encouraged this morning to hear Art Hanson talk about the geographic situation display in the tower because this is the first meeting I've been to where it's been indicated that that's part of the FAA's plans. That has been really kind of a concern because I think the test at Denver proved that that's a very useful piece of equipment. Ultimately, it is the type of display that you might want to send up to the airplane.

The LLWAS TDWR message format I've mentioned, the use of the ASR9 I've mentioned and I think the only other thing I didn't hear this morning but I'm sure it will be coming along is the presentation of the TDWR display on the controller's BRITE. At the last meeting I attended I also heard that was not part of the FAA's plan but I certainly hope that becomes part of their plans.

The development of a controller training program as these systems get implemented is a must. They might not be able to make pilots and meteorologists out of them but we can at least the controller thinking towards the pilot problems. But more than that, we also have to continue to develop a data link so that we take some of the work load off his shoulder.

The 1988 season is over and I think everybody breathes a sigh of relief when the thunderstorm season ends, but we've got several more years to go where a situation

at most of the airports are going to be exactly the same as they were at Dallas Forth Worth in '85 and in Kenner in '82. So there's no substitute for awareness and training and that's the only thing we're going to have going for us in the next few years so we have to concentrate on them.

Session II. Perspective

Wind Shear Procedures and Instrumentation
W. W. Melvin, Airline Pilots Association

WIND SHEAR PROCEDURES AND INSTRUMENTATION

W. W. Melvin
Air Line Pilots Association

A recent study by Dr. Angelo Miele and the Aero-Astronautics Group of Rice University entitled "Effect of Pitch Rate on Abort Landing Windshear Encounters" shows that high pitch rates (greater than 3/4 degrees per second) will adversely affect flight path performance in strong wind shears close to the ground (Figures 1 through 5). This study of a typical jet transport aircraft for the landing case is an offshoot of the Optimal Trajectory Studies by the Rice University group which is funded in part by NASA Langley under the direction of Dr. Roland Bowles.

This should call to question the advice in the FAA Wind Shear Training Aid (WSTA) for pilots to rotate "at a normal rate" to a prescribed pitch, a procedure known as the constant pitch technique which was also used for the Rice University study. "Normal rate" is defined and understood by pilots to be 2 to 3 degrees per second which is much too fast for the landing case in a severe shear. In modest wind shears, pitch rate has little effect upon flight path performance. A higher pitch rate may be required for initial rotation at takeoff, but for encounters after takeoff an initial pitch reduction followed by a gradual pitch increase more closely approximates an optimal trajectory.

Borrowing a figure from Dr. Rene Barrios' presentation (Figure 6) which is in close agreement with the optimal trajectory studies at Rice University, it is evident that his altitude profile for deliberate flight at the stick shaker angle of attack (curve no. 2) is a very poor strategy. One must question then the advice from the WSTA to remain at the stick shaker angle of attack after it is initially encountered.

A new study by the Rice University group, yet to be published, should reveal the optimal trajectory after reaching the stick shaker angle of attack. This study is also an offshoot of the optimal trajectory studies and is funded by the Aviation Research and Education Foundation.

Examination of Barrios' curve no. 4 (constant pitch technique) shows that in this very strong wind shear there comes a time when the pitch can no longer be maintained at the prescribed value of 15 degrees and the flight path becomes negative. This effect is also shown in Dick Bray's paper. However, the WSTA tells a pilot that if at the target pitch and if the flight path is not satisfactory then the pitch should be increased. This can be an impossible task which holds out a false hope to pilots.

A correlation is shown in Figure 7 between aircraft performance and the F factor where aircraft performance is described by a constant airspeed. Also shown (Figure 8) are some limiting conditions of aircraft performance which reveal some values far

below the planned alert level of some aircraft warning systems. As pointed out by Dr. Bowles, in a wind shear an aircraft can in fact escape a condition exceeding the limiting value by trading airspeed. Nevertheless, some consideration to these limiting conditions should be given when designing alert levels and in prescribing escape procedures, especially recommendations to not change the high drag landing flap configurations in some cases.

What pilots want in wind shear instrumentation is a device which assists us. We will know about meteorological and operational conditions which the machine is not going to know. We do not need a decision maker, but rather an information device. Some devices, designed to not have false alarms, in fact do not have false alarms, but they do not protect against wind shear encounters. Others which do protect may have nuisance alerts. We accept this as long as we evaluate the alerts and use our judgement. We also want alerts on positive performance encounters and when on the ground.

Effect of Pitch Rate on Abort Landing Windshear Encounters

by

A.Miele, T.Wang,

C.Y.Tzeng, and W.W.Melvin
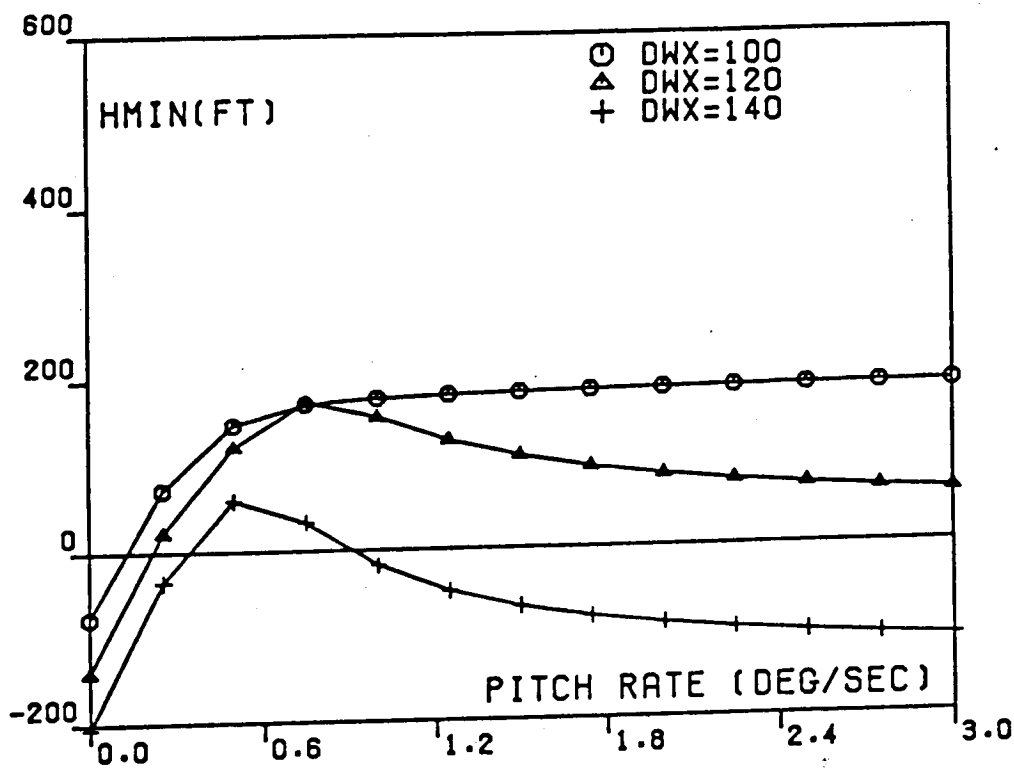
FIG. 3A. HMIN FOR DT = 0 SEC
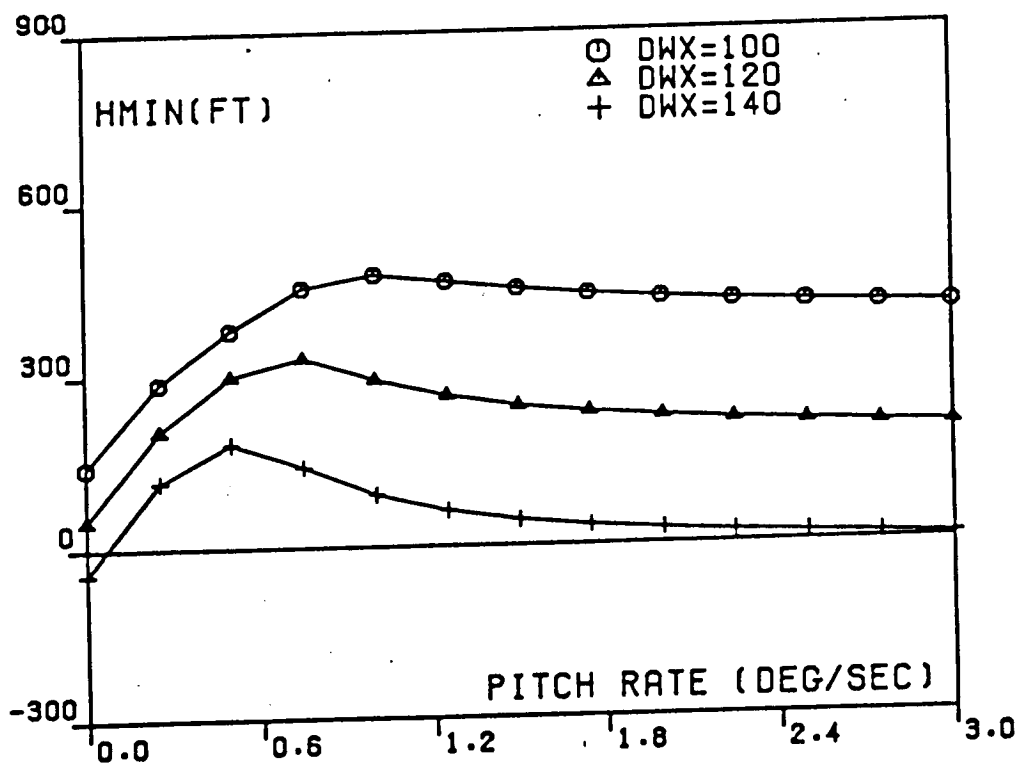AND HO = 200 FT.

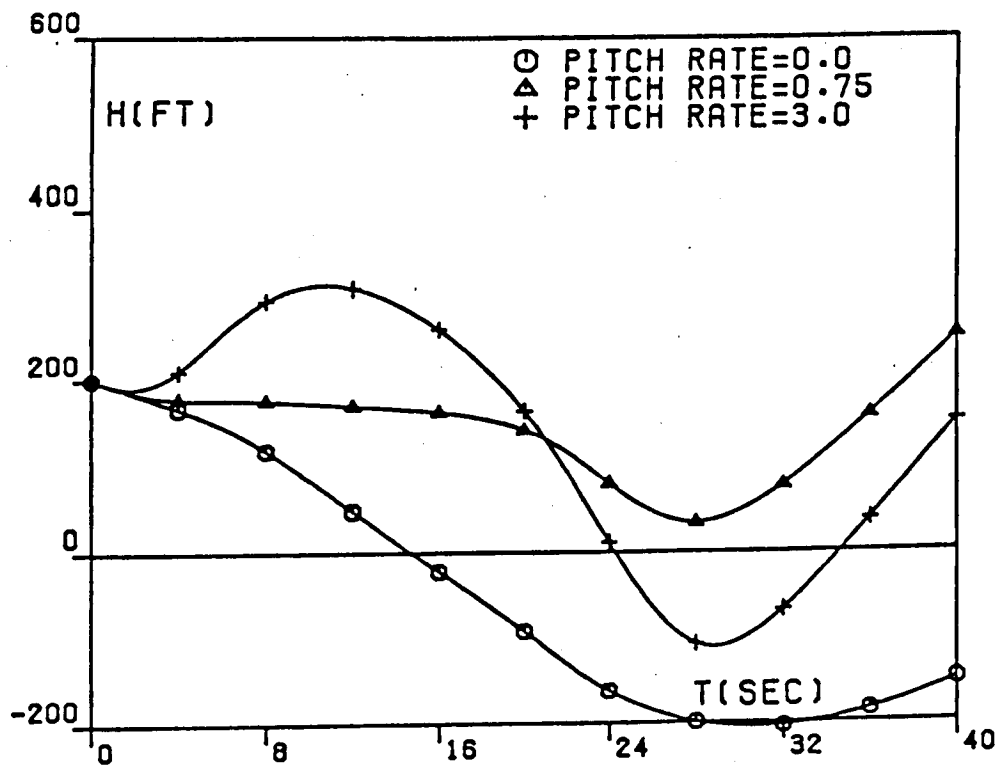FIG. 3B. HMIN FOR DT = 0 SEC
AND HO = 600 FT.

FIG. 2

FIG. 7A. TRAJECTORY COMPARISON, DT=0 SEC,
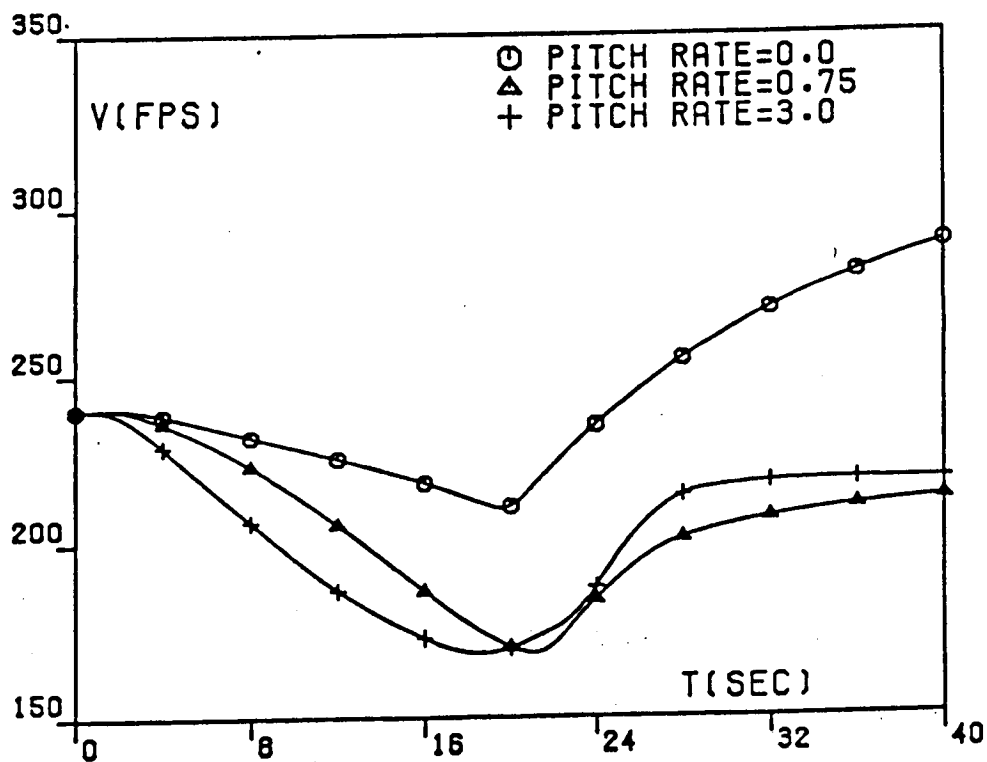H= 200 FT, DWX=140 FPS.

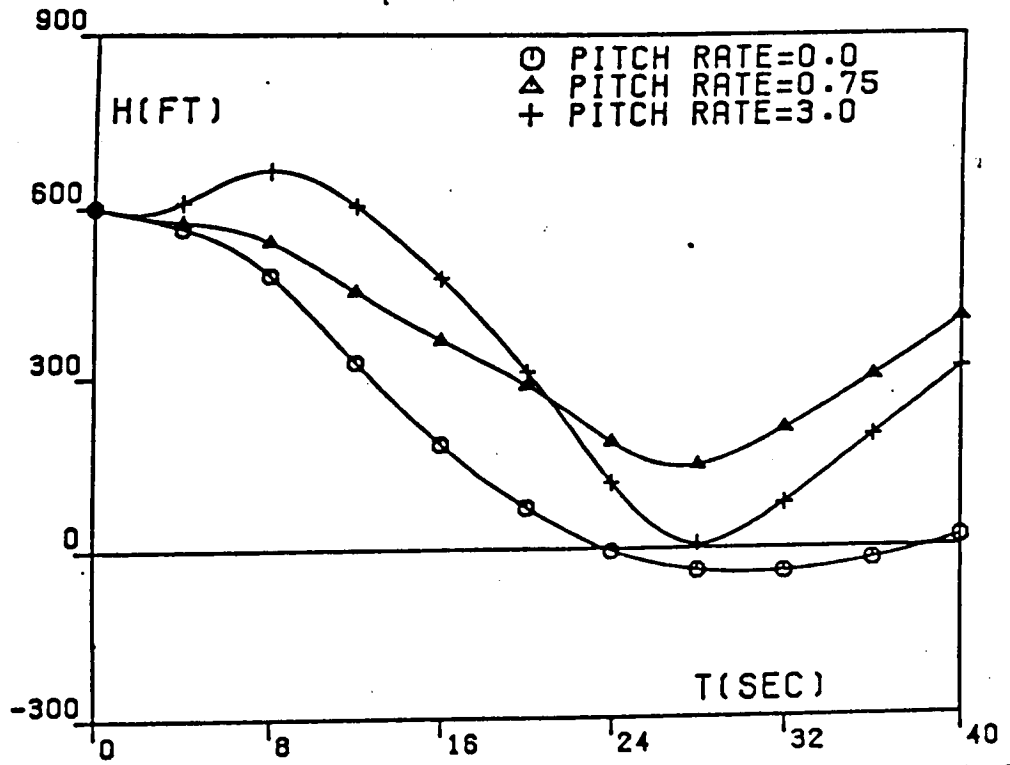FIG. 7B. TRAJECTORY COMPARISON, DT=0 SEC,
H= 200 FT, DWX=140 FPS.

FIG.3

803

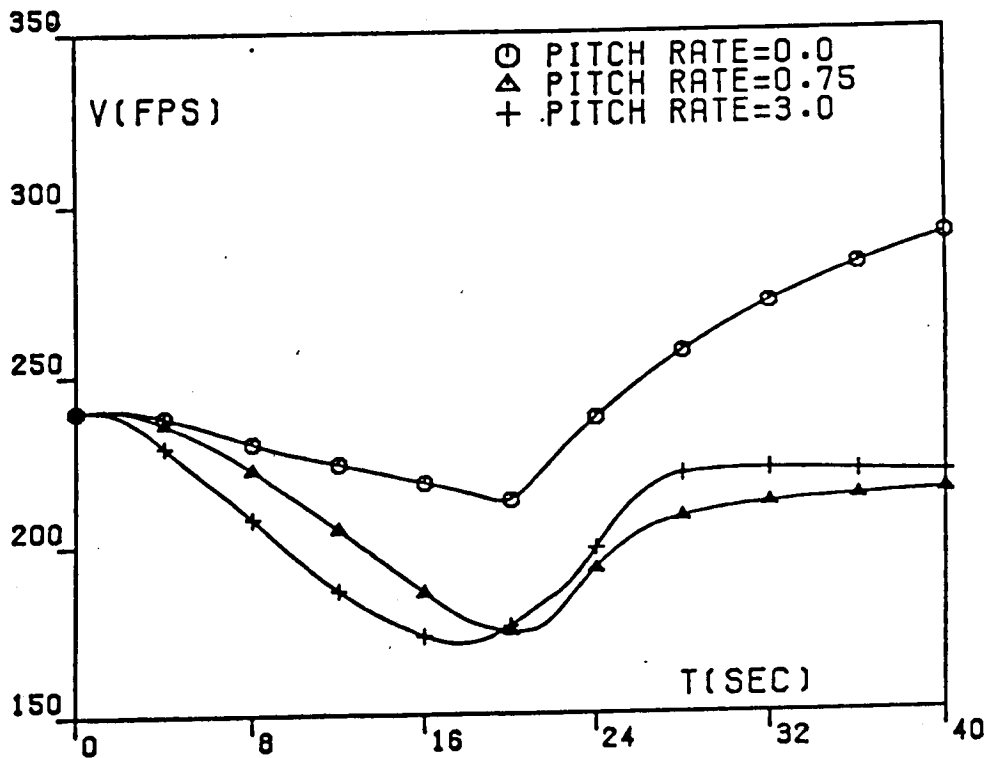FIG. 8A. TRAJECTORY COMPARISON. DT=0 SEC.
H= 600 FT. DWX=140 FPS.

FIG. 8B. TRAJECTORY COMPARISON. DT=0 SEC.
H= 600 FT. DWX=140 FPS.

FIG. 4

Conclusions for Abort Landing

* Variable pitch technique is superior to
constant pitch technique in terms of
minimum altitude and survival capability.

* Transitions from initial pitch to target pitch
is to be performed with gentle pitch rate.

* Best pitch rates are between
0.50 and 0.75 deg sec^{-1}.

* Variable pitch technique is closer
than constant pitch technique
to optimal trajectory behavior.

737 WINDSHEAR GUIDANCE
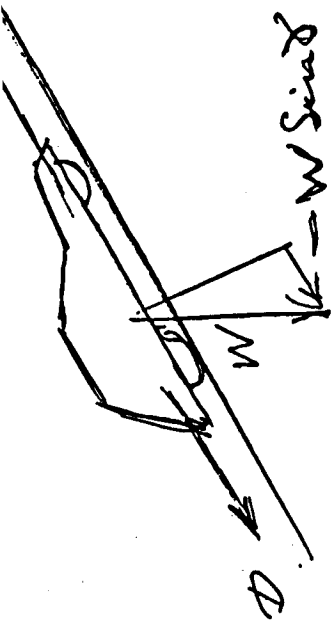## SHEAR: 20S ● 5KT/S, DNBURST: 18S ● 7KT

ALTITUDE IN FEET
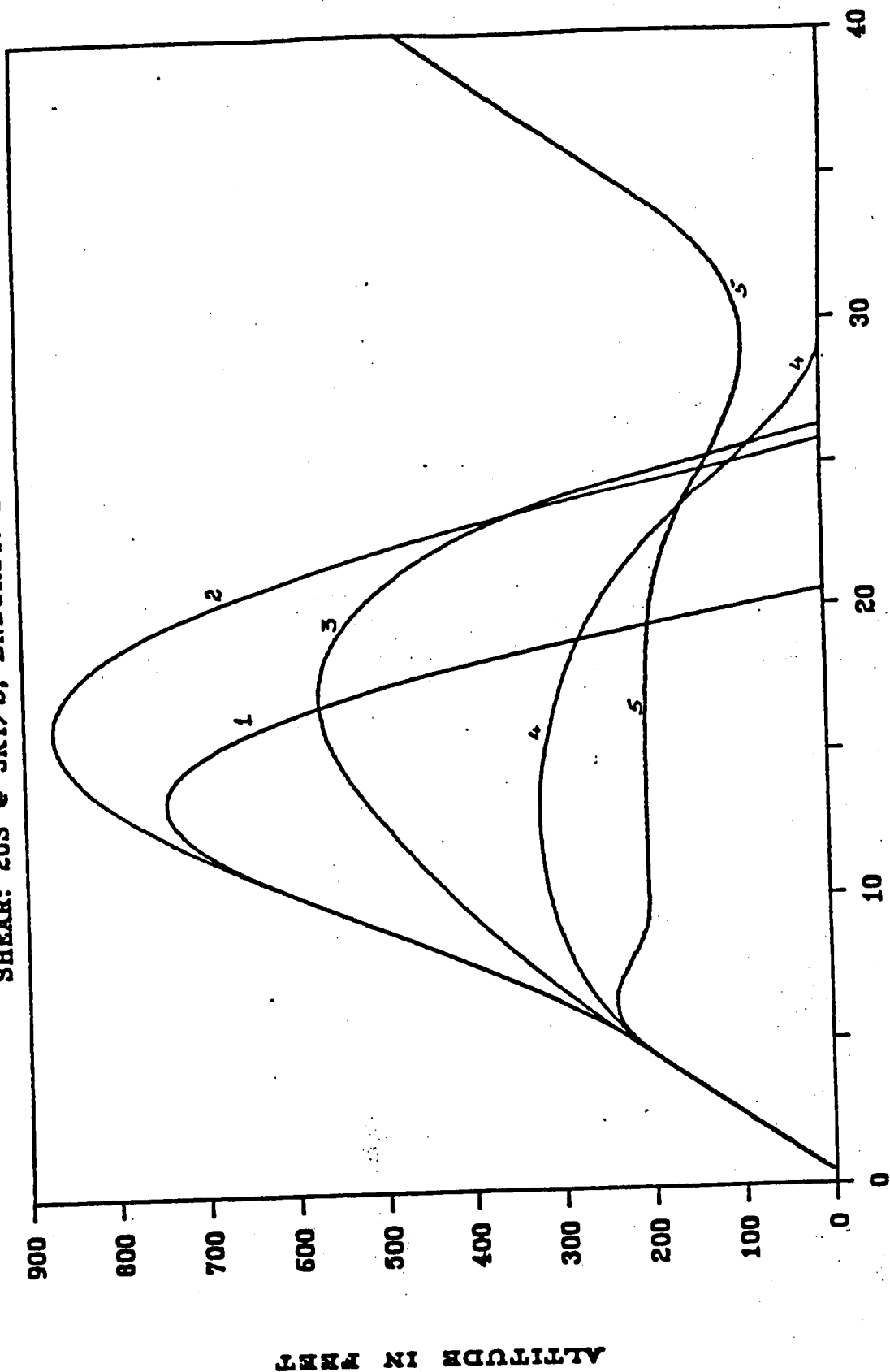
ELAPSED TIME IN SECONDS

$\underline{1}$ 1.1XVs $\underline{2}$ SS $\underline{3}$ Ah=0 $\underline{4}$ 15° $\underline{5}$ Honeywell

$$T - D = W \sin\gamma + \left(\frac{W}{g}\right)a$$

$$\frac{T-D}{W} = \sin\gamma + \frac{a}{g} = F$$

$$\frac{T-D}{W} = \frac{V}{Wb} + \frac{\dot{W}x}{g} = F$$

All Engine Climb Gradients

For Climb Limited Takeoffs

2 Eng. ~ .15

3 Eng. ~ .11

4 Eng. ~ .075

All Engine Landing Climb

.032

Engine Out Approach Climb

2 .021

3 .024

4 .027

Session II. Perspective

Airbus Wind Shear Warning and Guidance System
J. L. Bonafe, Airbus Industries

AIRBUS WINDSHEAR WARNING

AND GUIDANCE SYSTEM

J. L. BONAFE

AIRBUS WINDSHEAR WARNING AND GUIDANCE SYSTEM

1. AIRBUS WINDSHEAR PHILOSOPHY

From its first designed airplane, Airbus considered mandatory an help in the crew's decision-making process to initiate an escape manoeuvre and an help to successfully realize it.

For doing so forth all the Airbus airplanes are designed since 1975 including alpha-floor function and speed reference control law imbedded in the SRS box for A 300 and FAC and FCC for A 310, A300/600 and the A 320.

Alpha-Floor function takes into account airplane energy situation considering angle of attack and observed longitudinal situation in order to apply immediately the full power without any pilot action.

Speed reference managers airspeed and/or ground speed in order to survive a maximum in shear situation.

In order to comply with the new FAA regulation: Aerospatiale and Airbus developed more efficient new systems.

The following part of this presentation is a comparison between 1975 and newly developed system and explains how the new system does improve the situation.

2. WINDSHEAR GUIDANCE STRATEGIES

Analog A 300's and digital A 310's and A 300-600's (AFCS standards 5-6-7) have a very well known and similar SRS guidance law (Basic 1975 situation).

From our experience we confirm that this strategy is precise enough to survive many shears. In some strong shear cases it is however completed by an OEB procedure for disregarding FD bars at some point.

Safetywise analog and digital systems also do comply with the AC 25.12.

The basic Airbus Windshear guidance is favorable but can be improved.

We therefore defined a fully adaptive system that is able to cope with strong shears without any special procedure at all.

Initially we tried to develop and optimal guidance system but we reached very quickly for impossible solutions :

First : optimal guidance procedures really are different from one shear to another, in some cases the system initially even demanding to dive.

Second : guidance is really optimal if we have the full knowledge of the whole shear pattern before penetrating it.

Third : which in fact is the conclusion of the second point : in any shear encounter an optimal guidance system has to bet on the future.

For all these reasons we developed a repetitive and adaptive survival strategy (Figure 2) adapted to all performance problems in typical shear conditions.

The system is derived from the A 300 SRS System (Figure 3) improved by a vertical speed floor protection, by a Vmini protection and by a stall protection.

This Control law realizes the survival strategy (Figure 4) whatever be the longitudinal or vertical shear stressing the aircraft capability in take off or go around conditions.

The Control law implemented in the FCC's SRS take off go around mode is available on flight director, CWS or command.

In shear conditions and when shear intensity stresses the aircraft's capability, the SRS law will progressively adapt its control to a survival strategy :

1 - Basic vote (n° 1) will control airspeed (Vsel + 10 Kt) with a vertical speed decreasing to zero.

2 - Vote n°2 then over controls vote n° 1 and commands a slightly positive vertical speed with an airspeed decreasing down to V stick shaker plus a small Δ.

3 - Vote n°3 then overcontrols vote n° 2 and vote n° 1, controls airspeed at Vss + Δ. The altitude will be reduced until the shear decreases.

Whatever commanded strategy, pitch attitude demand is limited by a stall protection to avoid impending any stall situation.

3 - AIRBUS GUIDANCE SITUATIONS

The most severe shears proposed in AC 120.41 windfield models were simulated in the take off phase both with the initial A 300 SRS system and with the newly developed windshear guidance system (called here control of aircraft's energy).

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Comparing figures 5 and 6 we conclude that the new system really does improve the situation but that the initial A 300 SRS was already well effective in its capability to cope with a real encounter.

Figures 7 and 8 emphasize the advantages presented by the new system in theoretical shear conditions: an adaptive control law maintains the aircraft inside the operational flight envelope and uses maximum airplane capability to achieve this.

The control law is implemented in the A 300-600 AFCS since A/C MSN 420 and for the A 310 it will be in the 89 first part. In principle the control law is available for retrofit to all aircraft from the digital fleet.

From simulation experience we know that for take off with derated power or for the landing case a successful escape manoeuvre can be accomplished if max power or go around decision is promptly decided upon entering the shear.

This remark just to focus on the absolute need for a tool to trigger the crew's decision-making process to initiate escape.

Windshear detection can provide this valuable help; but what do we have to detect what nuisance warning level should we reach to maintain an acceptable level of crew confidence with regard to the warning.

All those aspects were kept in mind to define an Airbus windshear warning philosophy from in-flight incident/accident analyses.

4 - AIRBUS WINDSHEAR WARNING

Airbus targets (Figure 9) enhances AC 25.12 advices in detection, non-detection and performance nuisance warnings.

An evident design phyïosophy with regard to warnings was to define a wind severity factor computation (SF).

$$\frac{d\,Energy}{dt} = Weight \left[C^{te} - Airspeed \times \frac{d\,Wx}{dt} + g.W_z \right]$$

$$SF = \left[\frac{d\,Wx}{dt} - \frac{g}{Airspeed} \times W_z \right]$$

Intuitively this reflects the instantaneous loss of energy due to the global shear (longitudinal & vertical) if SF > 0.

Wx = longitudinal wind < 0 IF headwind

Wz : vertical wind < 0 IF down

Cte : function of A/C propulsion and aerodynamics (typical to each airplane)

G : gravity acceleration

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SF could be filtered and compared to a fixed threshold of 2.5 kts/sec or 0.13 g typically.

This conventionally adopted solutions was however rapidly abandonned due to a high level of nuisance warnings.

Wind variations knowledge is in fact the only parameter for a shear intensity evaluation but can never be the unique information in a windshear warning without duly taking into accound the aircraft's energy situation.

Windshear Warning computed without considering actual aircraft energy will lead, in certain cases of shear encounter, to very early warnings (the crew should identify them like nuisance warning) or will lead to too late warnings endangering an escape manoeuvre.

A good crew confidence level and a satisfactory escape manoeuvre capability can both be reached by a windshear warning as a reasonable compromise between "SF", aircraft's actual energy and a safe minimal energy.

5 - WIND SHEAR WARNING (WSW) COMPUTATION PRINCIPLE

The WSW is activated when the predicted aircraft's energy is below a predetermined minimal energy threshold (Figure 10).

This threshold corresponds to still air α floor protection in accordance with Flaps and Slats position.

$$\alpha^* = \alpha + \alpha_W$$

The predicted aircraft's energy depends on α^* which is obtained considering filtered angle of attack (AOA or α) corresponding to the actual aircraft's energy situation increased by equivalent angle of attack estimates (E.AOA.E) αW.

αW is an estimate of the energy loss foreseeable in the close future.

Note than the higher is AOA (α) the lower is the actual aircraft energy and the higher is E.AOA.E (αW) the higher will be the future loss of energy.

αw is obtained by a combination of equivalent angles of attack estimates :

   (a) - is the E.AOA.E due to instantaneous tailwind shear

   (b) - is a memorized E.AOA.E of the recent headwind shear.

   Generally a strong headwind is precursor of a strong decreasing shear.

   (c) - is an E.AOA.E decrease according to the mean wind observed in order to alleviate turbulence nuisance warnings

$\widehat{d}$ - is an E.AOA.E related to the observed vertical downward wind.

a, b, c, d, E.AOA.E's cannot be negative

b minus c cannot be negative

$\alpha W = a + d + (b - c)$ if $a > 0$

This windshear warning mechanization is schematized on figure 11.

In areas I, II and III, E.AOA.E's are computed but α^* is identical to AOA since $a \leq 0$ (no tail wind shear)

α^* combines AOA and αW

In area IV when vertical wind becomes negative : $d > 0$.

In area V αW increases when tailwind shear appears.

In that case WSW threshold is reached. It could have been reached in area IV if vertical wind intensity would have been higher. Similarly, it could also have been reached in area V with tailwind shear depending on shear intensity.

Simulator experience shows that short after lift off below 250 ft it is useful to trigger the WSW according to the tail shear for the case of a small margin regarding to 1,2 Vs. For clarification purpose, this function is not shown on these figures but is should be reminded that from lift off to 250 ft WSW can occur from α^* or from the $\widehat{a}$ branch only compared to a smaller threshold if Vc < 1,2 Vs + 5 Kt.

6 - PERFORMANCE WARNING

6-1 - PERFORMANCE NUISANCE WARNING

We considered both take off and landing cases but we limit intentionnally here our evaluation to the most disturbing case for air traffic and aircraft's utilisation : the landing case.

Nuisance warning probability by approach had been evaluated by simulating 500 automatic landings in tower wind conditions up to 40 Kts according to AC 20.57 A advices (automatic landing performance evaluation). Results are plotted figure 12.

Nuisance warning probability by approach is plotted for Airbus windshear warning and for the conventional windshear warning (properly filtered "SF" by a 4s lag refered in section 4).

We remind that a conventional windshear warning leads to a nuisance level of 10^{-3} per landing with a recommanded threshold of 0.13 g or 2,5 Kts, sec. We also note that the Airbus windshear warning leads to a nuisance level of 10^{-5} per landing with its implemented threshold of 11,5°. It is interesting to remember here that the US in service observed windshear probability encounter is about 10^{-6}.

6-2 - NORMAL PERFORMANCE WARNING

The Airbus WSW will alert the crew after an initial loss of longitudinal airspeed. The closer the selected airspeed to 1,3 Vs the smaller this initial loss before the warning is triggered (Figure 13).

Airbus WSW merely alerts the crew but has no activity on throttles or go around. the crew will decide according to the situation to pursue or to abort when landing or to triggering max power or not at take off.

α Floor protection is maintained on Airbus being the ultimate protection if the crew underestimates the situation at WSW.

For a windshear encounter case the general situation of Airbus WSW and α FLOOR are plotted on figure 14. One can notice the remaining energy margin at WSW and at α FLOOR.

In case the pilot wrongly selects too small a speed (1.25 Vs for example) the α FLOOR will in same cases of shear conditions intervene before the warning itself.

7 - AIRBUS WSW AND GUIDANCE IMPLEMENTATION

Since WSW is implemented in each FAC, aural and visual warnings can be tested on ground engines not running (Figure 15). In a case of shear encounter aural warning is activated and visual windshear red message displayed on each PFD. Warning can be activated at take off from lift off to 1000 ft and at landing from 1000 ft to 50 ft the visual warning will remain for a minimum of 15 s.

The general architecture is given figure 16.

8. A 320 IMPLEMENTATION

Aerospatidle and Airbus develop now very similar control laws for the A 320 taking advantage of managed speed "autothrottle" function for warning and guidance in order to further decrease nuisance warning level and increase safety in the escape manoeuvre initiation.

The A 320 system also takes advantage of the fly by wire concept for the guidance part. .

Fly by wire controls, if necessary, the plane into its maximum lift capability in the final part of the escape while avoiding any stall situation.

Certification is expected for 1989 in order to comply with the new FAA regulation process.
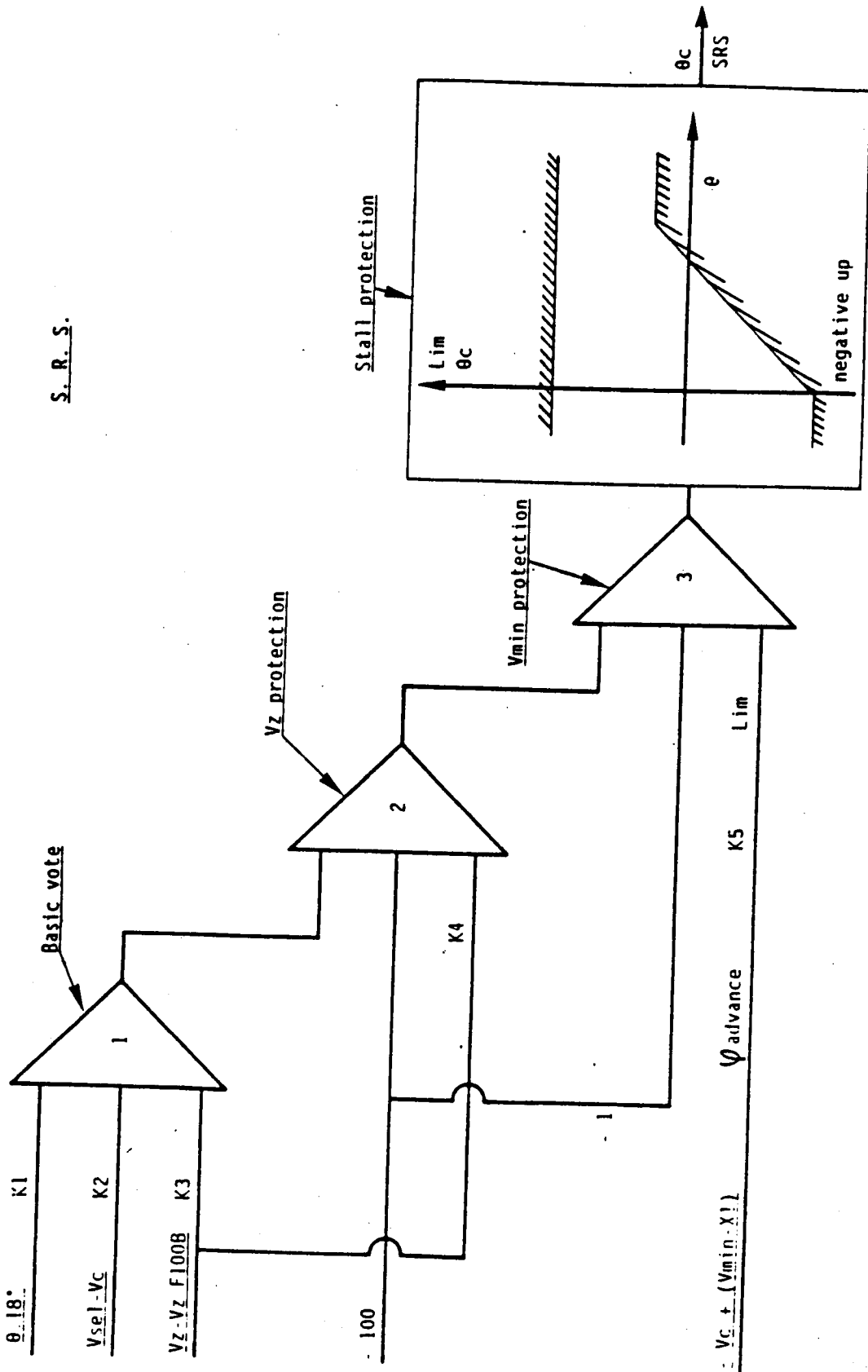
SRS   STRATEGIES

NO SHEAR CONDITIONS

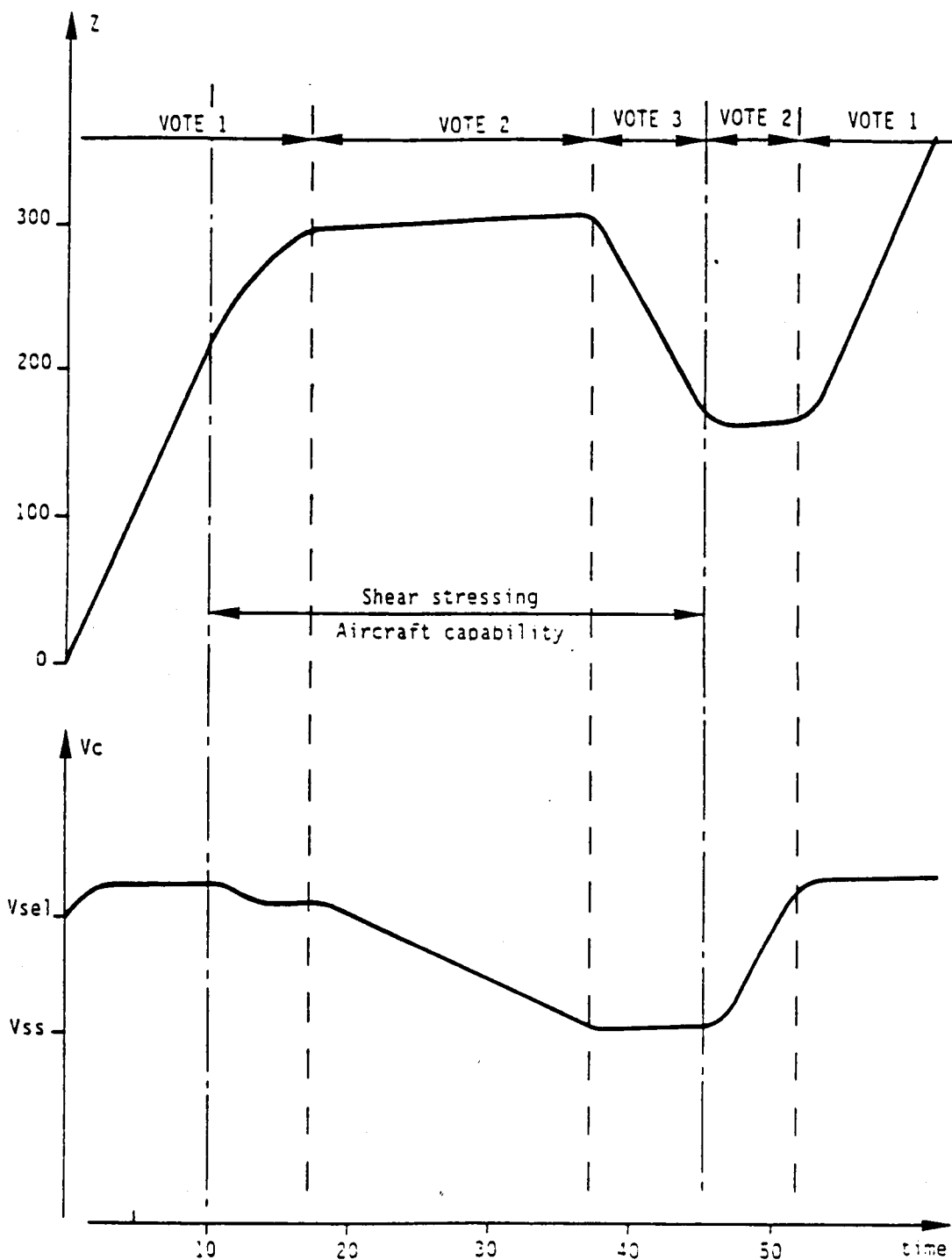|		
1	High thrust to weight ratio	• SRS controls pitch attitude max ϑ = 18° • Climbing slope = cte • VC increases > V2 + 10 Kts
2	Low thrust to weight ratio	• SRS controls airspeed VC = V2 + 10 Kts (VC = V2 or VEF if VEF>V2) EF case (Vertical speed > 2.4 % , ϑ < 18°)

SHEAR CONDITIONS

3	Shear does not stress aircraft capability	Strategy 1 or 2 will control AC according to shear intensity and thrust to weight ratio

4	Shear intensity stresses aircraft capability	Control strategy is self adapted to
		AC flight parameters :
		  1 - VC = V2 + 10 Kts control (VZ ↘▲0)
		  2 - VZ ≃ 0 control (VC ↘▲VSS + Δ)
		  3 - VC = VSS + Δ V control VZ < 0)
		until shear decreases.

Figure2

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S. R. S.

Basic vote

Vz protection

Vmin protection

Stall protection

θ.18° K1

Vsel-Vc K2

Vz-Vz F100B K3

1

- 100

K4

2

-1

φ advance K5 Lim

Vc + (Vmin·X!)

3

Lim θc

θc

e

negative up

SRS

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S.R.S. SURVIVAL STRATEGY

Figure 4

TAKE-OFF F / S 20 / 20   M = 150 t   XG = .25 V_2 = 154 Kts

AC 120.41 WIND FIELD Nr 6

Pitch att. deg.

Vz-M/S

A.O.A. deg.

ZFT / 10

VG - 100 Kt

VC - 100 Kt
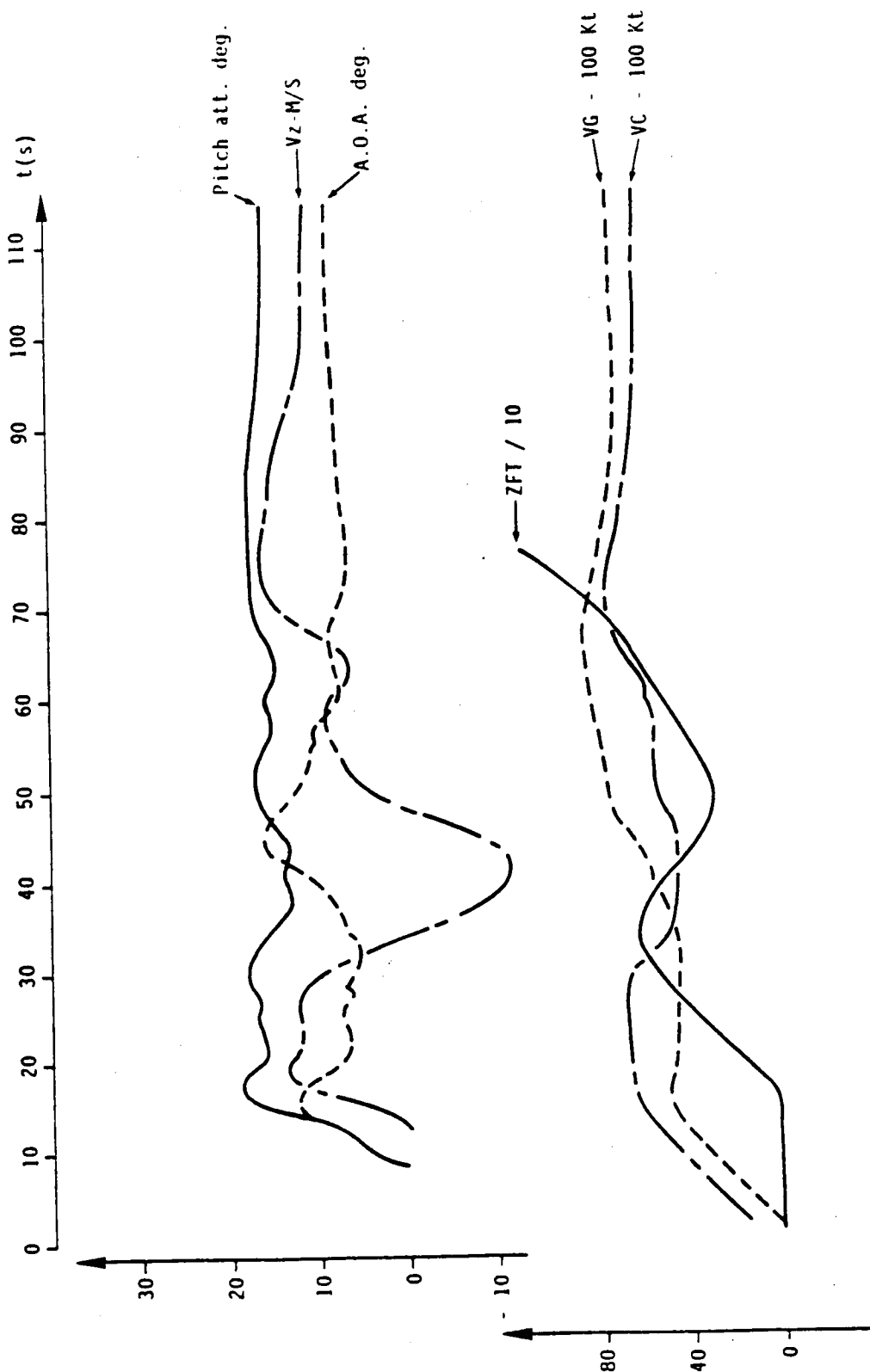
t(s)

Figure 5

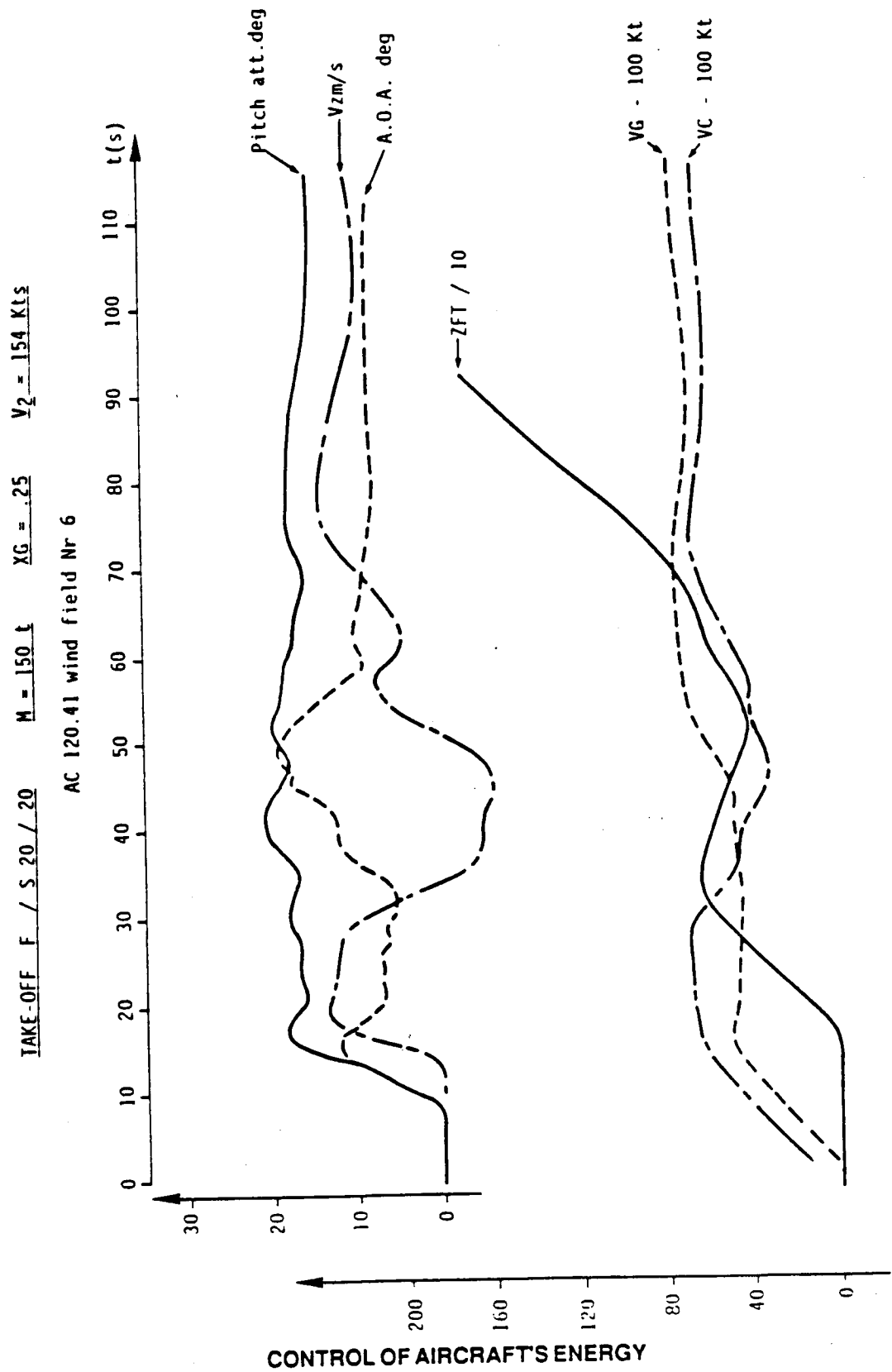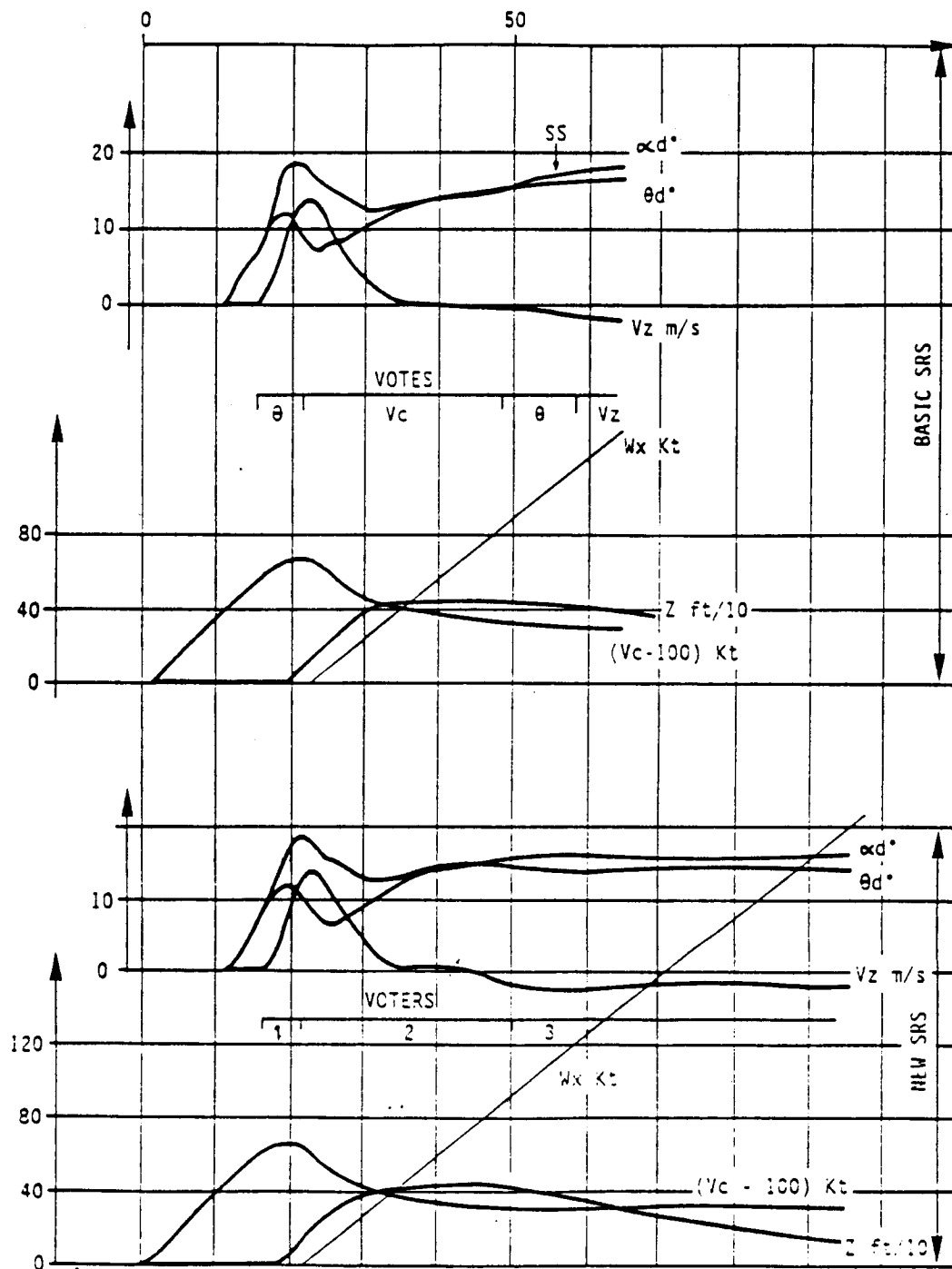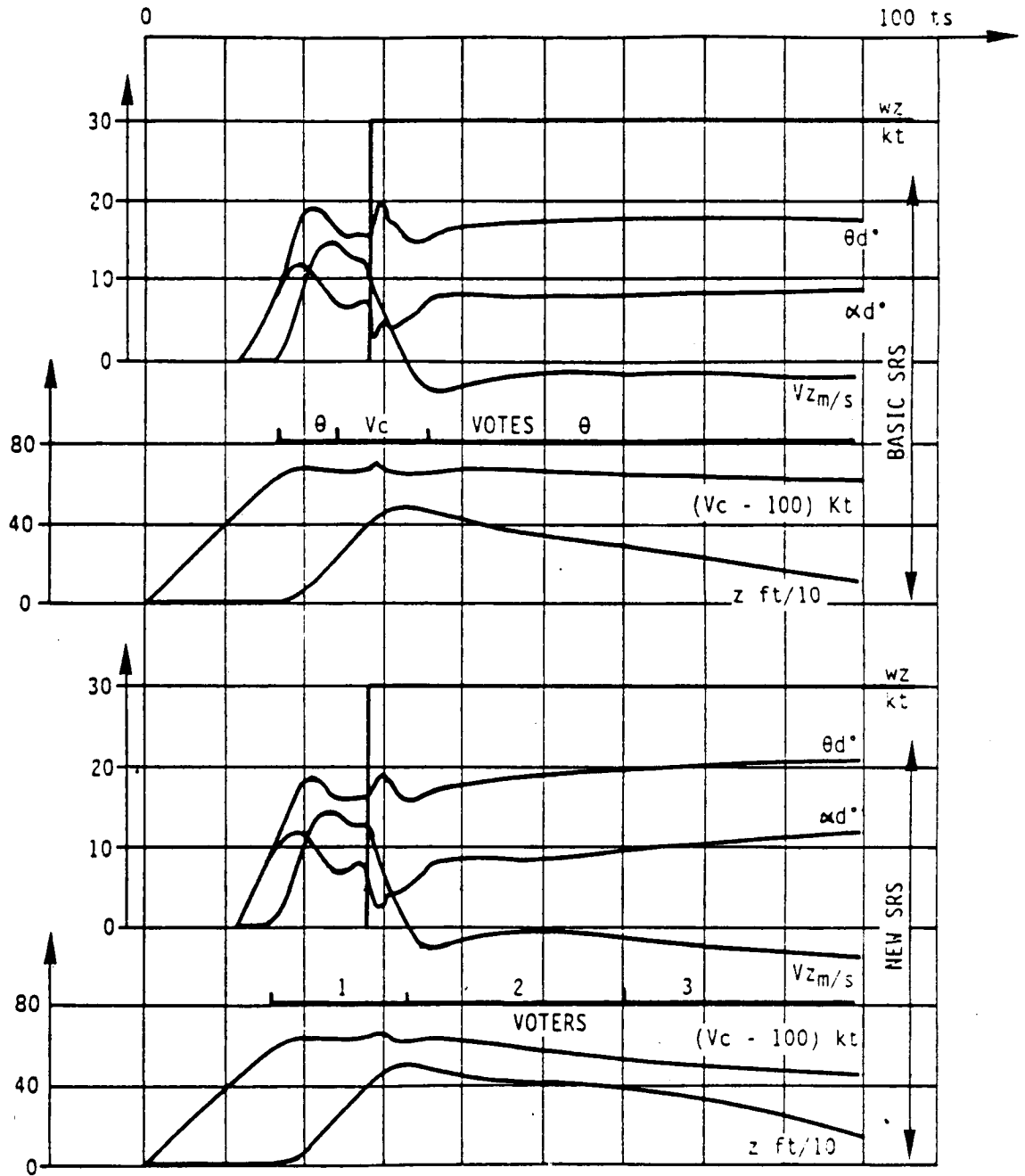CONTROL OF AIRCRAFT'S ENERGY

Figure 6

TAKE-OFF±ISA.SL

LONGITUDINAL TAIL SHEAR

Figure 7

TAKE-OFF   ISA-SL

VERTICAL DOWN WIND

Figure 8

AIRBUS WSM SYSTEM TARGETS

Performance

- Detect 10^{-6} or $< 10^{-6}$ simulated cases

- If no detection show the good behaviour of the aircraft

Nuisance

Warning due to active Failure

5.10^{-6}/approach or take off

Lack of warning due to latent Failure

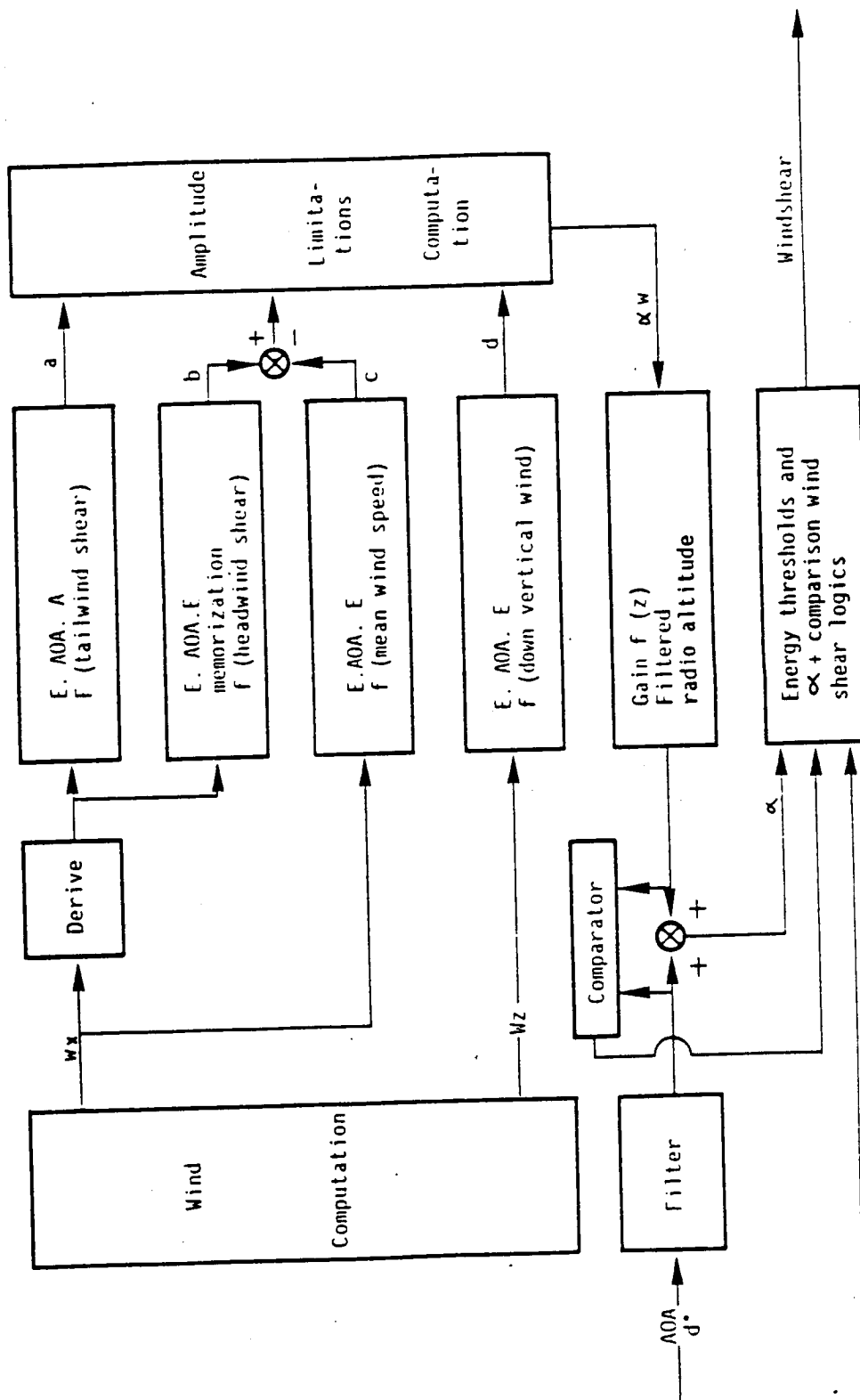6.10^{-6}/approach or take off

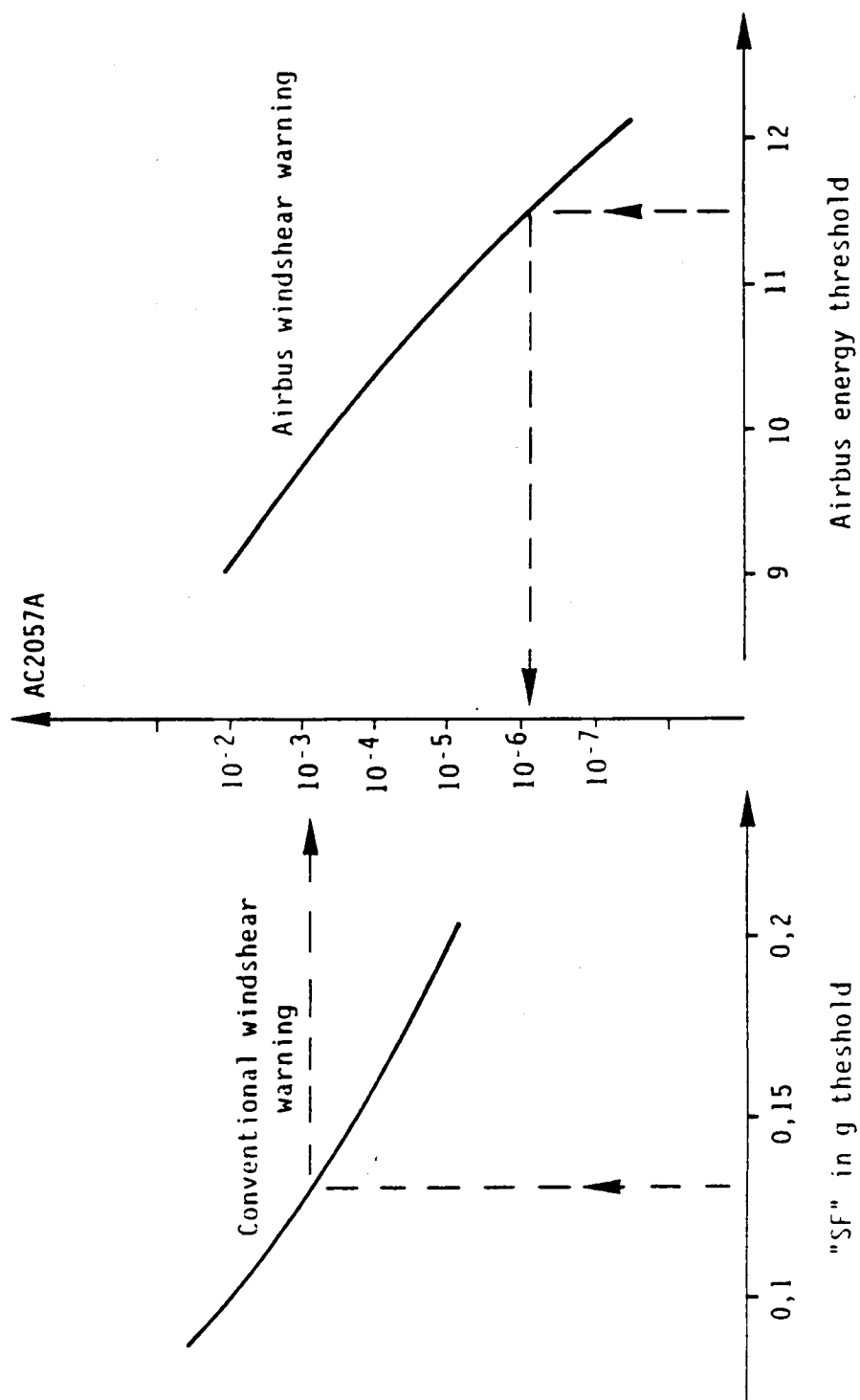Performance nuisance warning

10^{-6}/approach.

Figure 9

AEROSPATIALE WINSHEAR WARNING

COMPUTATION PRINCIPLE

Figure 10

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Figure 11

SIMPLIFIED ALGORITHM

NUISANCE WARNING PROBABILITY

AC2057A

Airbus windshear warning

Airbus energy threshold

10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}

9   10   11   12

Conventional windshear warning

"SF" in g theshold

0,1   0,15   0,2

LANDING CASE
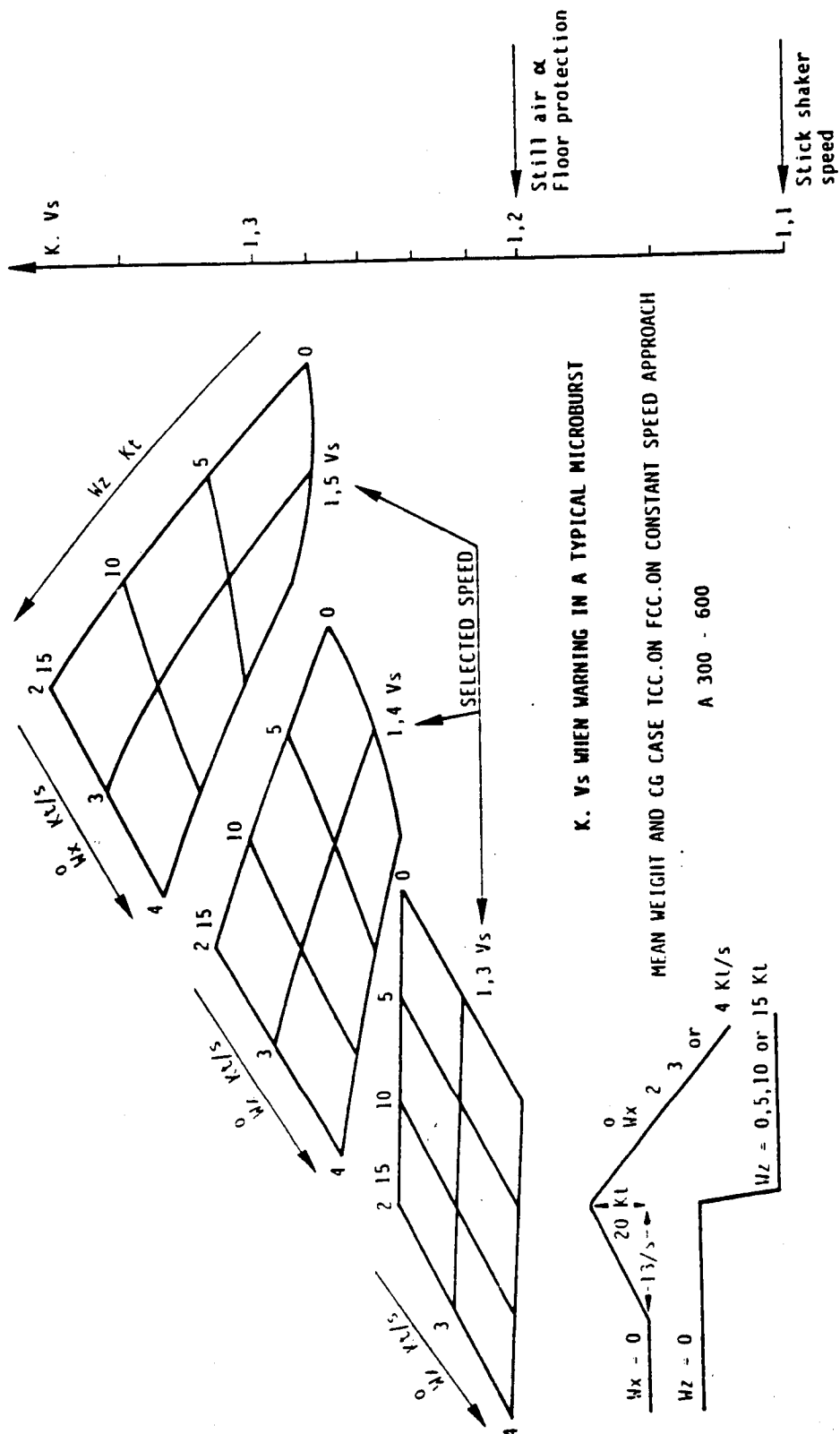
Figure 12

Figure 13

MEAN WEIGHT AND CG CASE TCC ON FCC CMD

CONSTANT SPEED APPROACH A300-600

TYPICAL MICROBURST

Figure 14

GROUND TEST

1 or 2 FAC ENGAGED

Engine not running, perform Lamp test
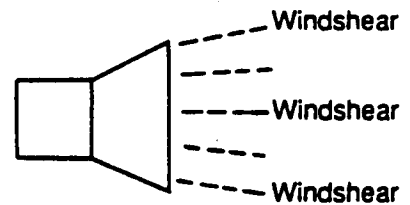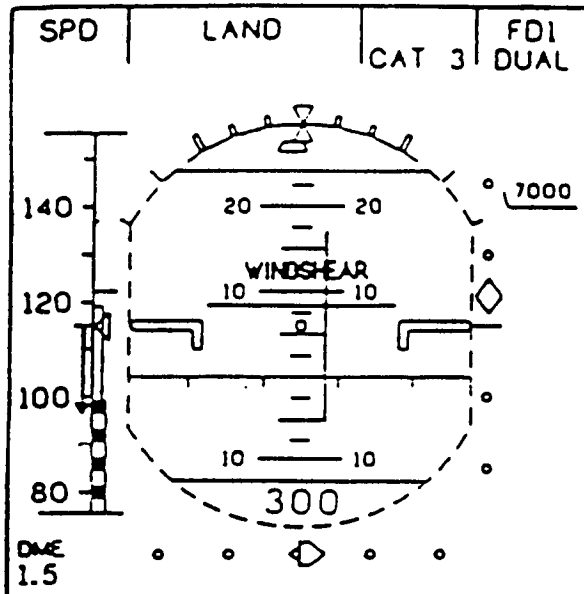
Windshear encounter non clean config.

and (from take off to 1000 Ft

or from 1000 Ft to 50 Ft)

and WSW available

1 or 2 FAC ENGAGED

Aural : Windshear 3 times when WSW gets on either FAC 1 or 2.

Visual : Windshear red on both PFD when WSW gets on either FAC 1 or 2 until WSW condition gets
off both FAC 1 and 2 plus 15 s.

AUDIO AND VISUAL WSW

Figure 15

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Figure 16

Session II. Perspective

The "Windvan" Pulsed CO_2 Doppler Lidar Wide-Area Wind Sensor
Rhidian Lawrence, Spectra Technology

MOTE
ND
NSING
STEMS BY
ECTRA
CHNOLOGY

N91-11705 p^{29}

527374

THE "WINDVAN" PULSED CO$_2$
DOPPLER LIDAR
WIDE-AREA WIND SENSOR

LIDARS FOR REMOTE WIND MEASUREMENT

```
┌──────────┐     ┌──────────┐     ┌──────────────┐
│  LASERS  │─────│ TR SWITCH│─────│  TELESCOPE/  │──→ TO
│          │     ├──────────┤     │   SCANNER    │  ATMOSPHERE
│          │     │ RECEIVER │     │              │
└────┬─────┘     └────┬─────┘     └──────┬───────┘
     │                │                  │
     │           ┌────┴─────┐            │
     │           │          │            │
┌────┴─────┐  ┌──┴───────┐  ┌──────────┐ │
│ CONTROL  │──│ DOPPLER  │──│  OUTPUT  │ │
│          │  │PROCESSOR │  │          │ │
└────┬─────┘  └──────────┘  └────┬─────┘ │
     │                           │       │
     └───────────────────────────┴───────┘
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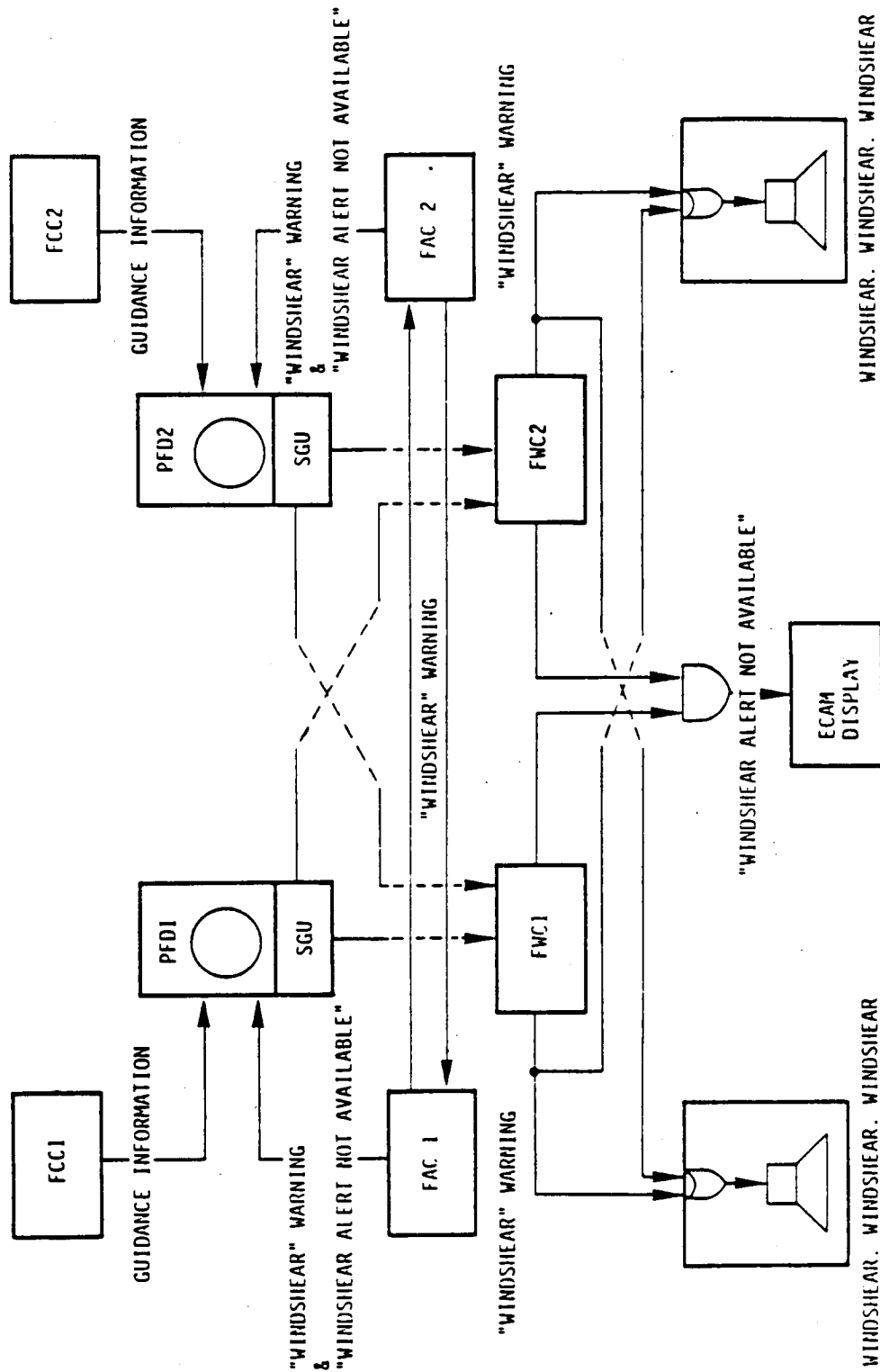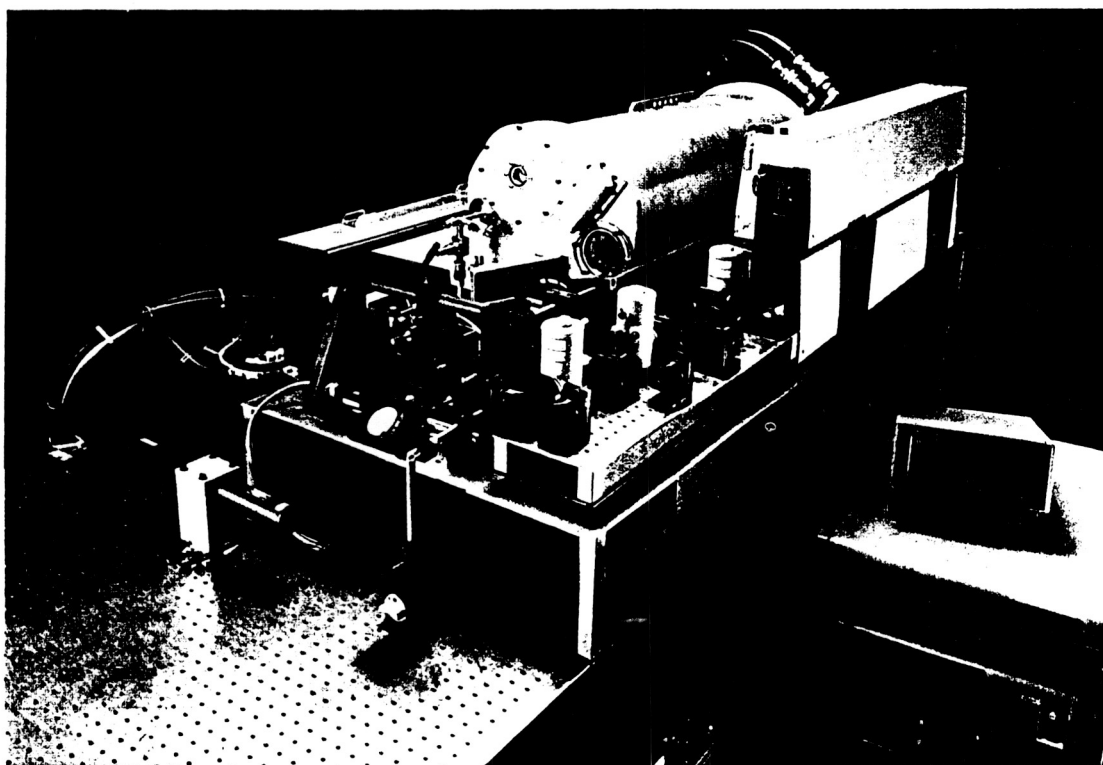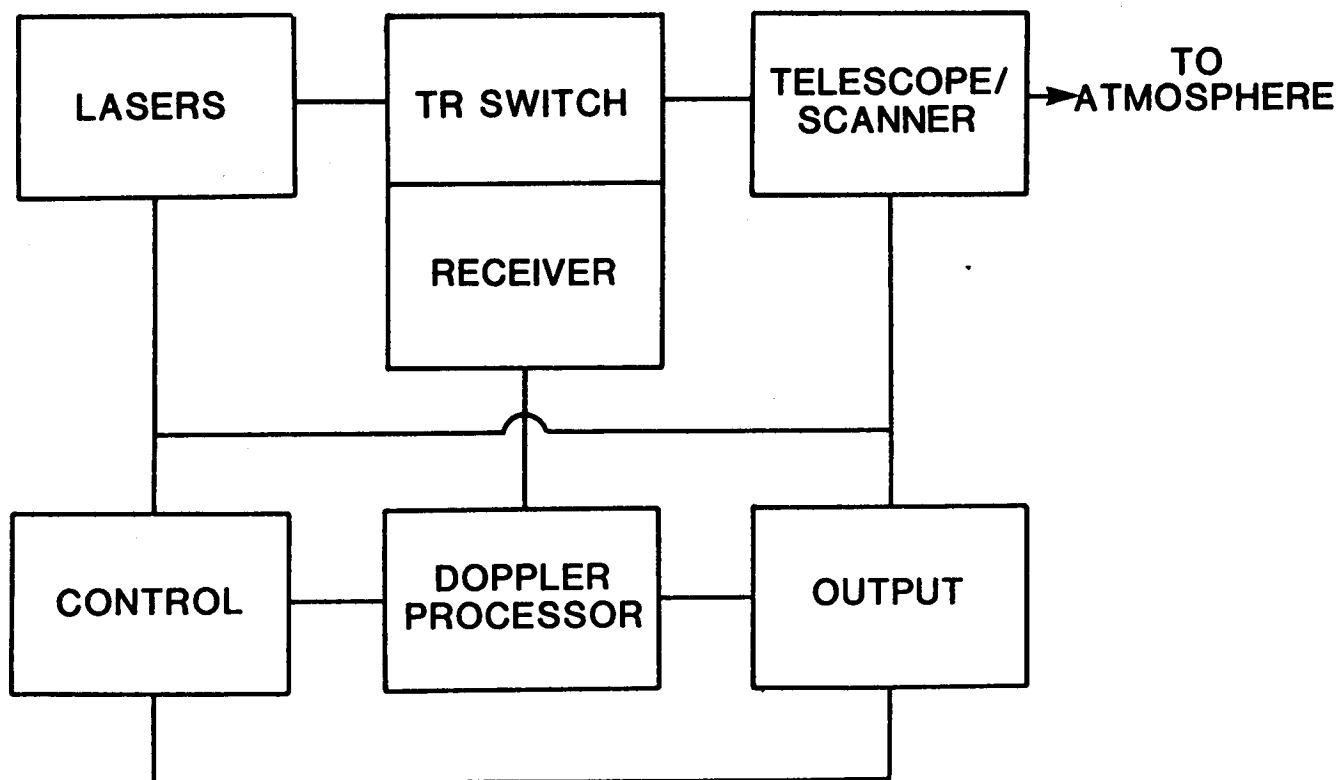
A Doppler lidar transmits a pulse of light into the atmosphere via a telescope/scanner. The Doppler-shifted collected light is photomixed with the light from a reference local oscillator on the surface of a photodetector, which results in an electronic signal at the Doppler frequency. The required optical beam switching is achieved by the Transmit Receive (TR) switch. The frequency content of the RF signal is measured by the Doppler Processor and normalized to yield the radial velocity of the target. A control computer directs the operation of the lasers, scanner, processor and output devices.

COMPLETE MOBILE WIND MEASUREMENT SYSTEM DEMONSTRATED BY NOAA/WPL

OTHER APPLICATIONS

● Doppler Laser Radar
● DIAL Measurements of Pollutant Concentration

SPECTRA TECHNOLOGY, INC. PROVIDES:

● Complete Integrated Systems
● Advanced Lasers
● Other Lidar Components

PULSED CO_2 DOPPLER LIDAR SPECIFICATIONS

Listed are top-level hardware and performance specifications. A detailed set of specifications reflecting your particular requirements will be provided on request.

LASERS: The transmitter laser is a 2 J per pulse, 50-Hz PRF injection-controlled TE laser operating at 10.6 μ. Injection and local oscillator lasers are 5-W cw devices.

TELESCOPE/SCANNER: The transmit/receive telescope is a 0.30-m diameter off-axis Cassegrain. Beam scanning is accomplished by an AZ-EL mount to achieve complete hemispherical scanning. Scan pattern is programmable.

RECEIVER/TR SWITCH: Transport of transmit beam to the atmosphere, received beam from the atmosphere to the detector and of the local oscillator to the detector achieved by a ZnSe Brewster plate, $\lambda/4$-plate TR switch. Detector is thermoelectrically cooled.

DOPPLER PROCESSOR: Real time digital Doppler processing. Particular algorithms can be tailored to customer requirements.

CONTROL: Total instrument control by a central computer.

OUTPUT: Per customer requirements. Options include hard copies of tabular and graphical wind profiles, computer-controlled color displays and magnetic tape.

INSTALLATION: Per customer requirements, laboratory, mobile or airborne.

TIME FOR VERTICAL WIND PROFILE: 30 s

RANGE RESOLUTION: 150 m

MAXIMUM RADIAL WIND SPEED AND ACCURACY: ±50 m/s, ±0.3 m/s.

PRICE: Subject to your installation requirements. Spectra Technology would be pleased to quote on your precise requirements.

PERFORMANCE EXPECTATIONS:

A CO_2 Doppler lidar is by its very nature a clear air device with limited propagation capabilities through, e.g., fog and clouds. In clear air conditions, the range of the device is dependent on the prevailing atmospheric aerosol content. Typically, the standard performance model could be expected to achieve a range in excess of 25 km in the boundary layer and routinely obtain wind profiles to 10 km altitude (i.e., the troposphere).

EXTENDED PERFORMANCE MODEL:

For support of high value missions at long range and upper altitude an extended performance version is recommended. Extended performance is achieved in several ways:

- Increased pulse energy and repetition rate (to 5 J and 100 Hz)
- Increased telescope aperture (to 1 m for 10 dB sensitivity gain)
- Isotopic gas mix (to minimize atmospheric absorption and increase aerosol reflectivity)

Incorporation of all features results in a sensitivity increase of up to 30 dB. STI would be pleased to quote on your precise requirements.

WIND SENSING USING A DOPPLER LIDAR

AEROSOLS

WIND

DOPPLER-SHIFTED
BACKSCATTERED ECHO

DOPPLER LIDAR CONCEPT

PULSE OF COHERENT
LASER RADIATION

Wind sensing using a Doppler lidar is achieved by sensing the Doppler content of narrow frequency laser light backscattered by the ambient atmospheric aerosols. The derived radial wind components along several directions are used to generate wind vectors, typical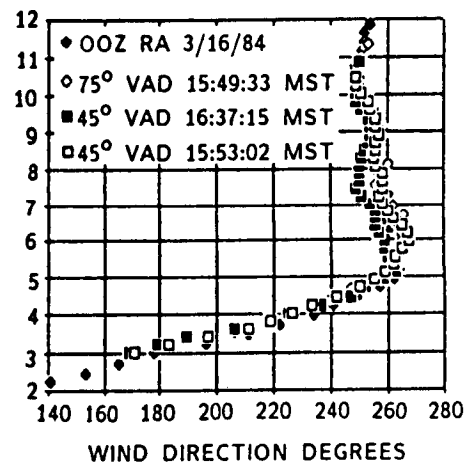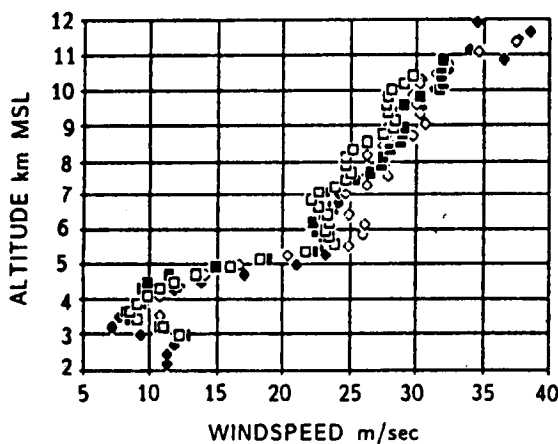ly using the Velocity Azimuth Display (VAD) method described below. Range resolved information is obtained by range gating the continuous scattered return. For a CO_2 laser (10.6 μ) the Doppler velocity scaling factor is 188 kHz/ms^{-1}.

0 TO 360°

2β

BEAM POSITION ON CIRCULAR SCAN, $a \longrightarrow$

V_v = vertical wind component

$\quad = \overline{V}_o / \cos\beta$

V_h = horizontal wind component

$\quad = V_t / 2 \sin\beta$

a_h = direction of horizontal wind component

VAD Principle of Operation
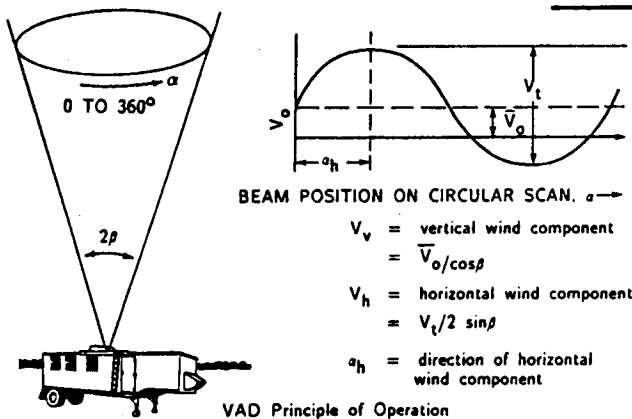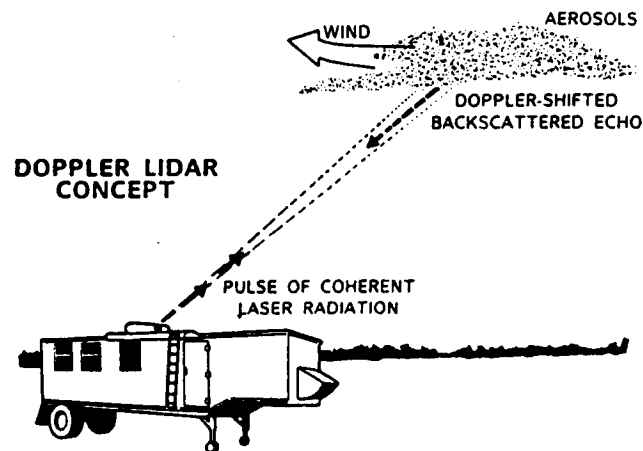
In the VAD scan method the zenith angle of the pointing direction is fixed and and its azimuth is continuously varied through 2π. A spatially uniform wind field at a particular altitude yields a sinusoidal variation of the radial component vs. azimuth. The amplitude, phase and DC component of this sinusoid yield the horizontal wind speed, direction and vertical component of the wind respectively. In a nonuniform wind field the Fourier components of the variation yields the required information.

ALTITUDE km MSL

WINDSPEED m/sec

◆ 00Z RA 3/16/84
◇ 75° VAD 15:49:33 MST
■ 45° VAD 16:37:15 MST
□ 45° VAD 15:53:02 MST

WIND DIRECTION DEGREES

An extensive series of measurements at the National Weather Service Forecast office at Stapleton airport, Denver has demonstrated excellent agreement between Doppler lidar and Rawinsonde outputs.

DATA: Courtesy National Oceanic and Atmospheric Administration/
Wave Propagation Laboratory

EXAMPLES OF DOPPLER LIDAR OUTPUT

(Courtesy of the National Oceanic and Atmospheric Administration/ Wave Propagation Laboratory)

In the PPI display at the right, the velocity in each range-azimuth cell is color coded according to the scale at the right. The green-blue scale indicates flow toward the lidar (located at the center) and the yellow-red scale flow away from the lidar. This particular example indicates west/north westerly flow. Range rings are at 10-km intervals. Wind measurement to a range approaching 25 km is indicated.
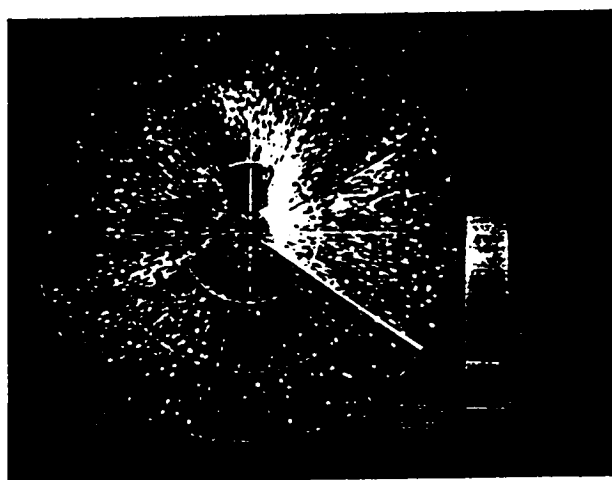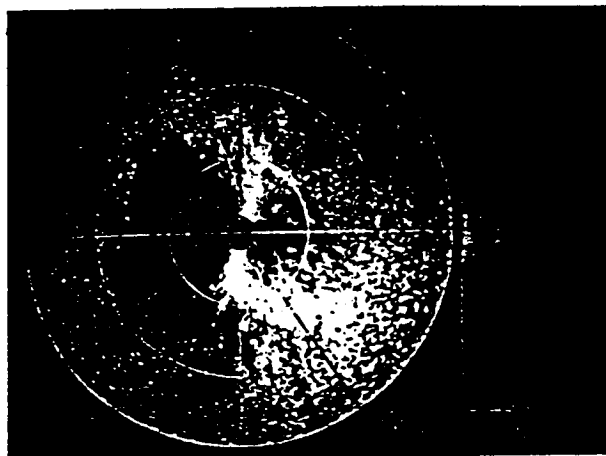
The dramatic feature at an azimuth of 280° (as shown in the photograph on the left) is the outflow from a down burst. This phenomenon when it occurs within the landing corridors at airports can have catastrophic consequences. The blacked out sector, toward the SSE, is due to terrain blockage.

The photograph on the right shows scan and processor flexibility, which allows tailoring of output to unique requirements. In this example, a raster scan at a range of 3.2 km, down a canyon, shows the nocturnal jet. Note the shear that occurs at the plateau level above the canyon.
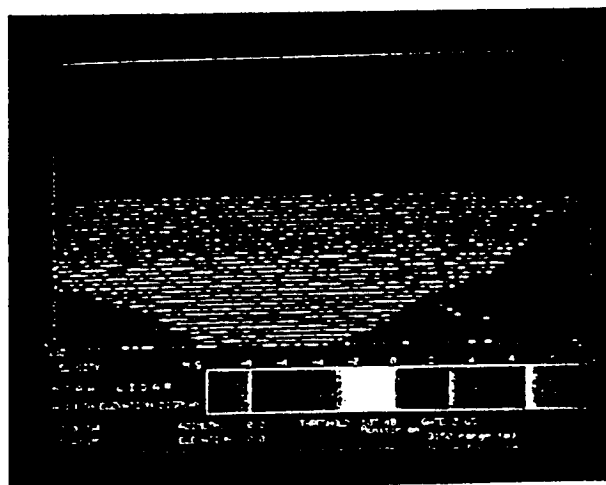
Session III. Topics

Low-Cost Airborne Lidar for Wind Shear
Loren D. Nelson, OPHIR

PRESENTATION OUTLINE

• **OVERVIEW OF PHASE II SBIR CONTRACT**

• **LIDAR NUMERICAL MODELING RESULTS**

• **OPHIR LIDAR DESIGN STUDY**

• **FIELD TESTING AND 1989 TDWR**

• **CONCLUSION**

ophir

ophir CORPORATION

Loren D. Nelson, Ph.D., CCM
Vice President
7333 West Jefferson Ave., Suite 210
Lakewood, Colorado 80235
Telephone: (303) 986-1512

Research and Instrumentation for the Atmospheric Sciences

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PRIMARY PHASE II TECHNICAL OBJECTIVES

- ENGINEERING DESIGN OF LIDAR SYSTEM

  — 95%

- CONSTRUCTION OF LIDAR SYSTEM

  — 50%

- LABORATORY TESTING FOR S/N,
  HETERODYNE, AND DOPPLER
  PERFORMANCE

  — 0%

- INITIAL FIELD TESTING

  — 0%

- LARGE SCALE FIELD RESEARCH PROGRAM

  — 10%

- DATA ANALYSIS AND REPORTING

  — 0%

OPHIR LIDAR DESIGN

CW HETERODYNE SYSTEM

COMPONENT	CHARACTERISTICS	MANUFACTURER
LASER	5.6 W - 10.6 μm	Line Lite
TELESCOPE	DAHL-KIRCHIN f-18	CUSTOM
OPTICS	ZINC SELENIDE	II-VI Corp
AO MODULATOR	27 MHZ IF	Newport EO
DETECTOR	HgCdTe BW=50 MHz	New England Res.
SIGNAL PROCESSOR	HP Spectrum Analyzer	HP

849
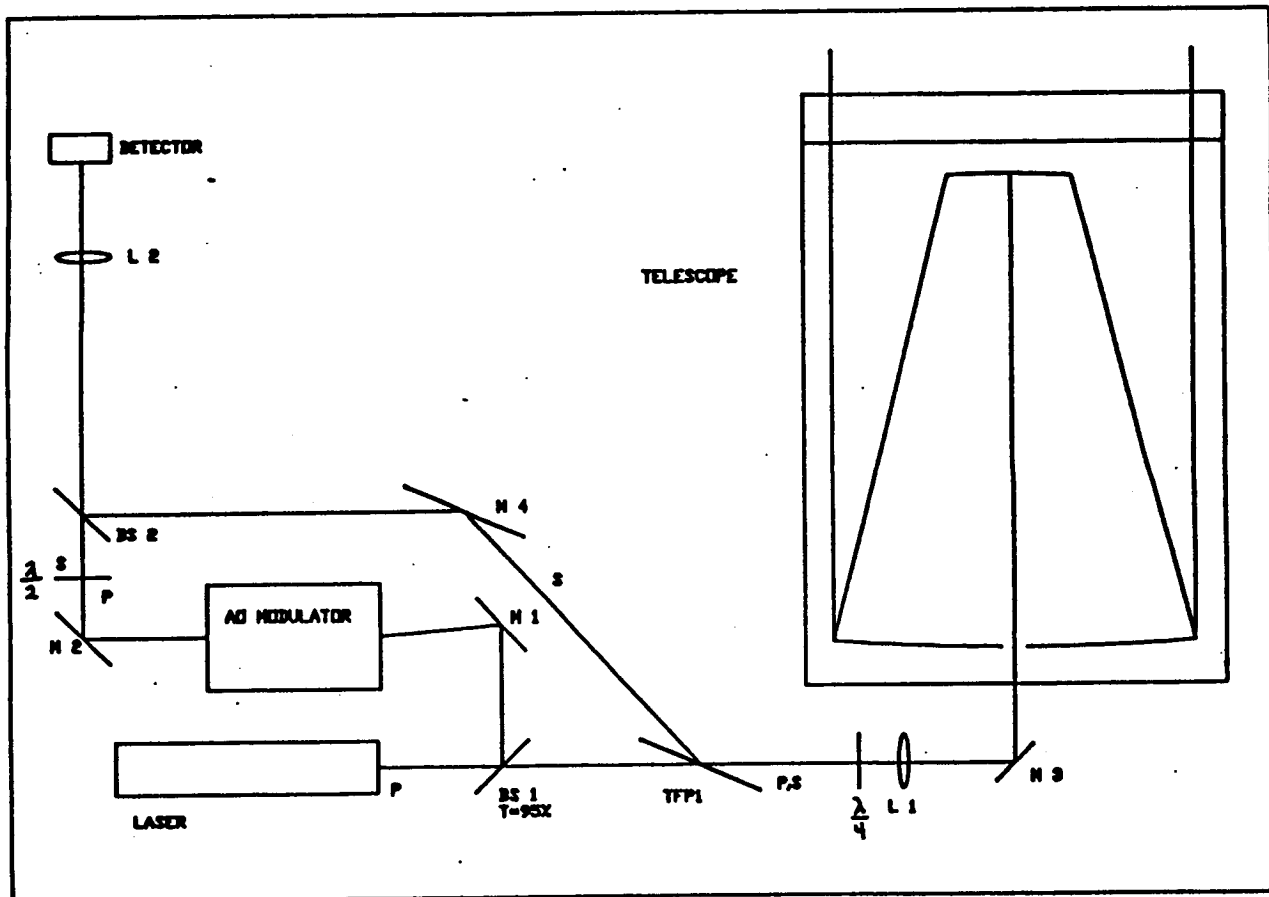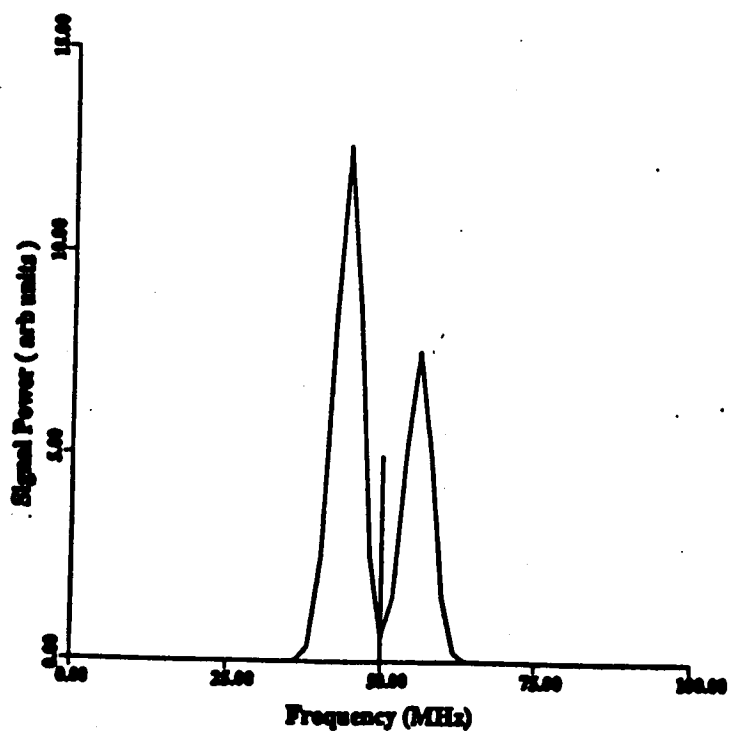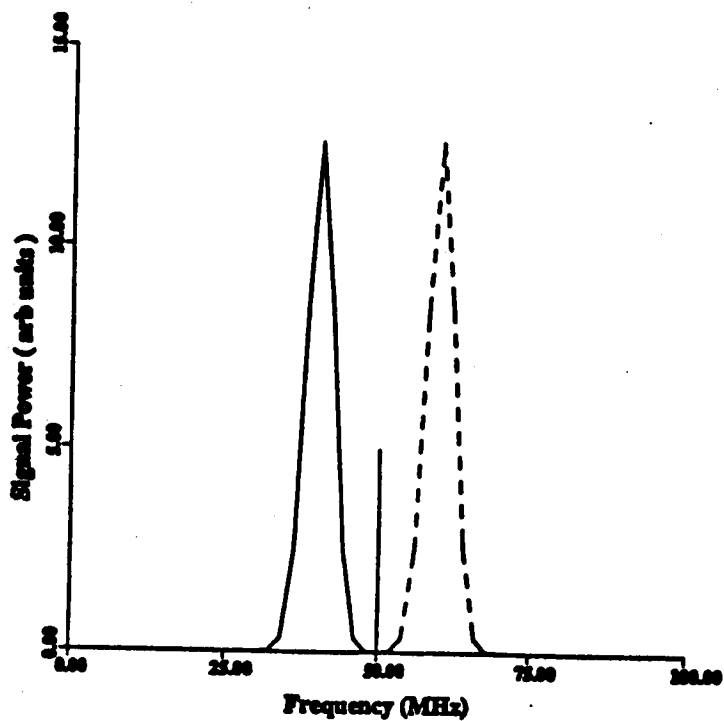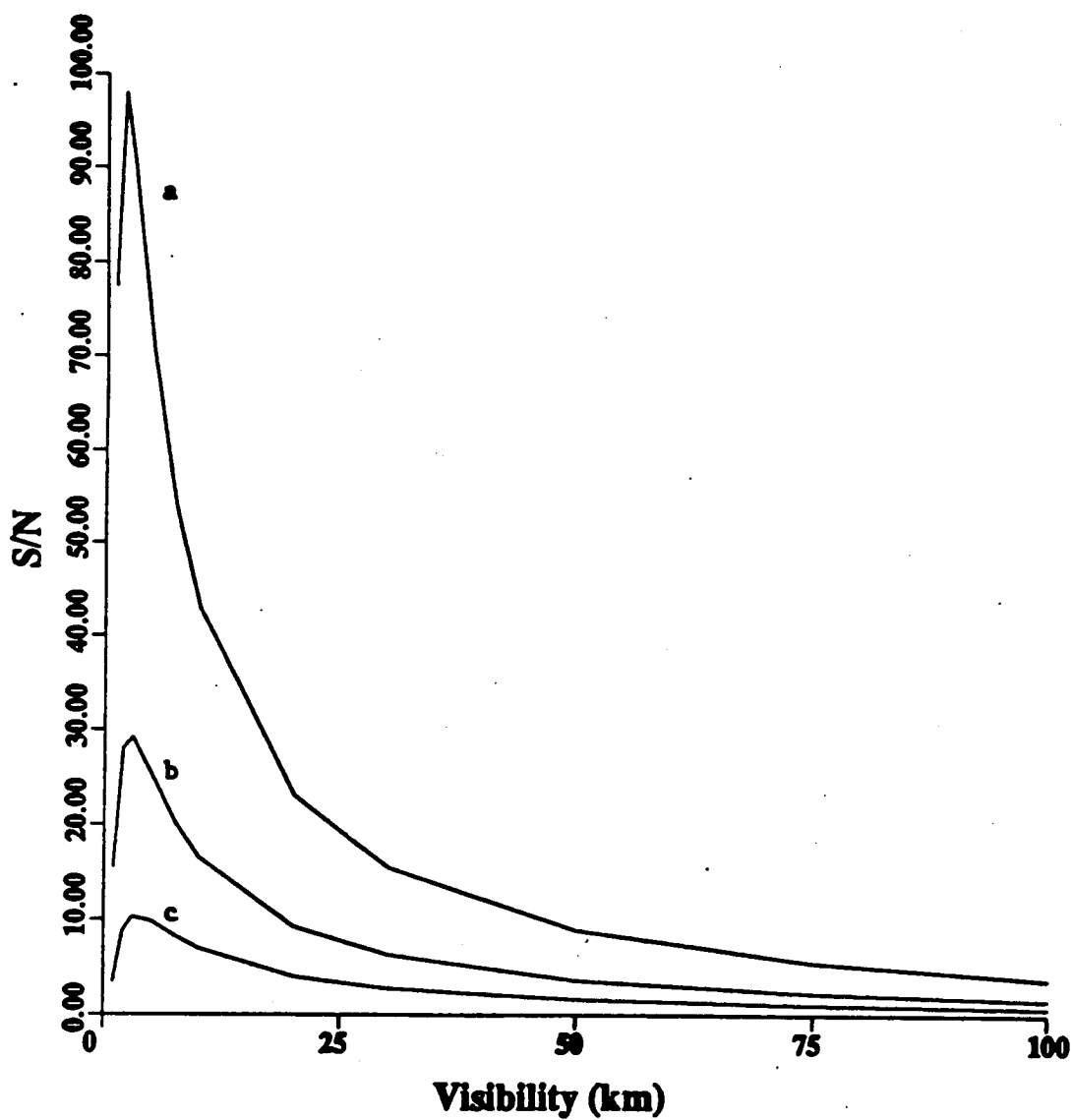
$a = 2000$
$b = 3000$ $\Big\}$ R_m
$c = 4000$

CALIBRATION TECHNIQUE

TOP VIEW

SIDE VIEW
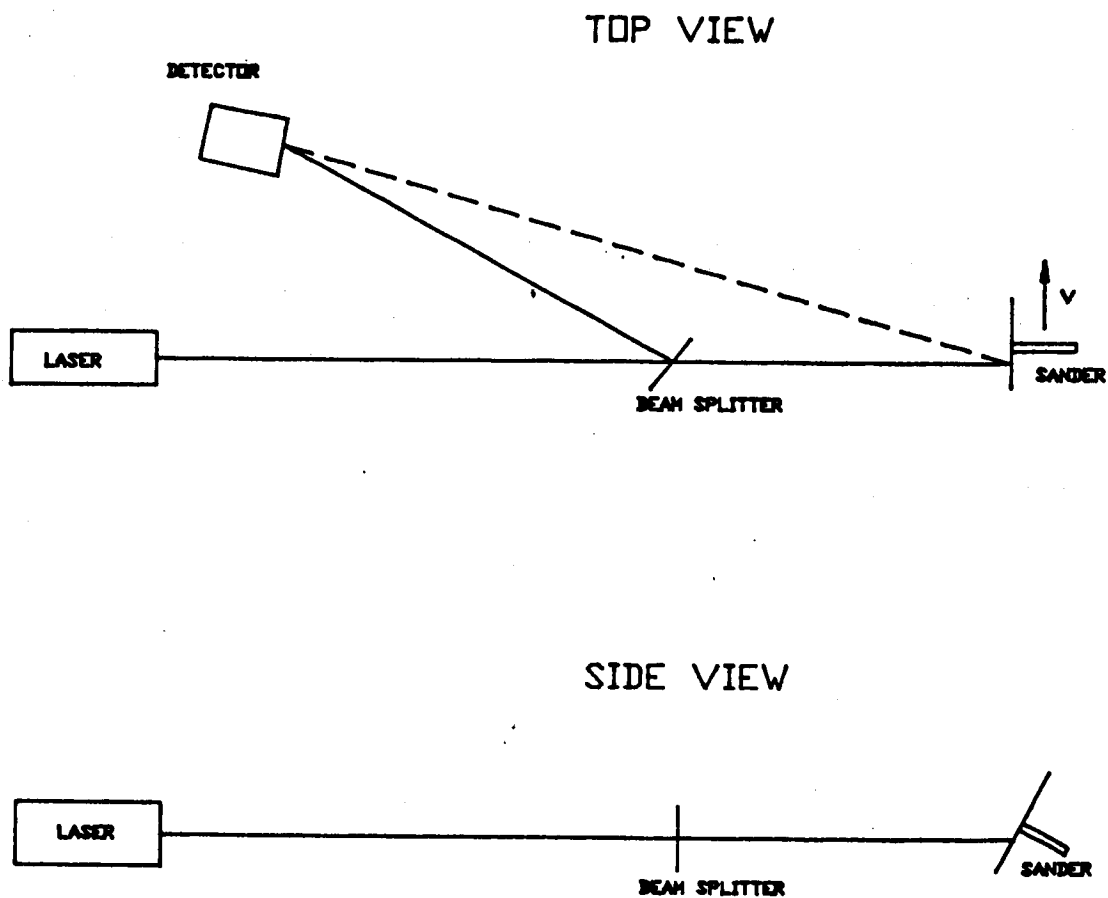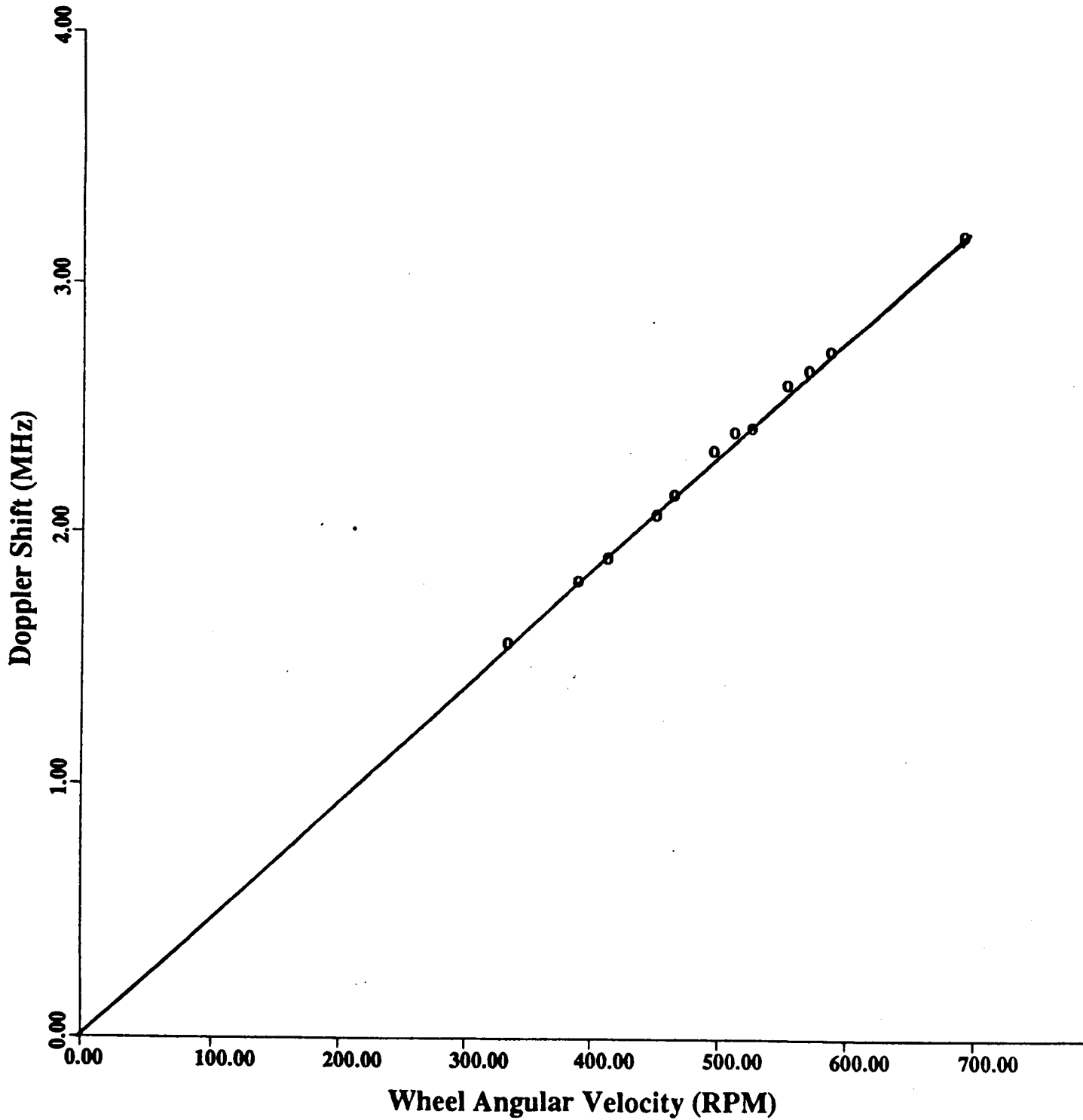
FIELD TESTING AND 1989 TDWR

- **DATES: MAY 15 - AUGUST 15, 1989**

- **LOCATION: DENVER STAPELTON AIRPORT**

- **PARTICIPANTS: NCAR, NOAA, UNIVERSITIES**

  — FAA, NSF, DOC sponsorship

  — LLWAS, Doppler radars and surface networks from NCAR and NOAA

- **STATUS: FIRST DRAFT OF OPHIR FIELD TEST PLAN COMPLETE**

  — Coordination through Jim Moore of NCAR/RAP

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FUTURE PLANS

CONDUCT GROUND FIELD TESTS

- Stapleton Airport

- Summer, 1989

SEEK FOLLOW-ON FUNDING

- Airborne Field Tests

- Ground Long-Term Evaluation

- Interface and Optimization

Questions and Answers for All Sessions

(answer already in progress) the comparison between Mesonet and radar observations and how those events break down in terms of strengths, I think they're referring to this comparison where in the 1988 cases there were two events that which were seen by a Mesonet which were missed by the radar and likewise, there were two events which were seen by the radar and missed by the Mezenet. Going back and checked on the strengths of those, both of these events which were missed by the radar were below 15 meters per second velocity differential and both of these events, also that were seen by the radar but missed by the Mesonet were also very weak around 12 meters per second.

Q: For the box with the matrix, where you've got both the 66 observations by the Mesonet and by the radar, do you have any differentiation as for strength in those?

A: Yes, and those are basically the .. now you're asking what's the distribution of all the microbursts that you saw between strong and weak? Is that right? And then, most of the microbursts were seen by both the radar and the Mesonet.

OK, so it's 97 and 77.

A: No, no, these are how well they were detected, this is just saying that for the stronger events, we detected 97% of them, for the weaker events, we detected 77%. If you want to get an notion of the distribution, basically there were 259 out of this sample, there were almost twice as many observations with strong events (.. goes over 15 [mps]) compared to those that were below. These two numbers here give you that answer. This is showing ..

Q: Yea, I see that but how does the 66 come off of that table?

A: We're looking at two different sample sets. The 66 events are the total number of microbursts. Each microburst event, each meteorological event counted once and that's over the 2 months of July and August. Right, and those are only those that fell within the region covered by both the Mesonet and the radar.

Well, then this chart is not pertinent to my question. Can we go back to the other chart?

You're asking of these 66, how many were weak and strong?

Of these 66, how many of them were above 15 meters per second in their maximum and how many of them of were below?

I don't have that number precisely, I would off hand guess roughly half were below and half were above.

Because earlier today, we heard .. not necessarily today but in the meeting, we heard some discussion about these weak ones, they can crash some airplanes too and from the beginning it was obvious that TDWR was going to do very well on the real strong ones but I would like to know what that split is on those 66 in terms of those that went above 15 meters per second and those that never went above.

Yes, I can answer that question for you off line, I think that relates a little bit to Fred Proctor's other question which is as you change the definition threshold for velocity differential, how do the statistics change between the numbers of dry versus wet microbursts and I think that's a little bit related to your question Norm. In general, looking over the last several years, our observations and looking at the distributions of strengths of microbursts, you see something like an exponential decaying distribution

so that the number of microbursts versus strength. We generally keep track of microbursts down to the threshold of roughly 10 meters per second and you've seen thousands of microbursts, I shouldn't say thousands, at least a thousand microbursts between 10 and 12 meters per second velocity differential. So far, I think we've only seen two microbursts with a velocity differential rate of 40 meters per second so there's a very rapid taper and as you raise that threshold Delta V for windshear, you're willing to accept as a microburst, you're number of events drops off rapidly. There have been a number of studies looking at a correlation between surface reflectivity and strength, basically you see no correlation at all. Whatever ratio a dry to wet microburst, which is very regionally dependent, the delta V threshold doesn't appear to make any difference. We haven't seen any correlation between outflow strength and surface reflectivity level. Does that answer your question Fred?

Fred Proctor Q: Have you actually looked at the numbers, I mean gone through and done the statistics on that? A: Both in the JAWS report and in our studies from last year and this year in Denver, we looked at scattergrams trying to look for a relationship between surface reflectivity and outflow intensity. Basically, there's no correlation whatsoever. Q: How about in other parts of the country? Have you looked at this yet? A: We have observations from Memphis and Huntsville in Alabama and I think that in the two years of observations we made there, I can't remember if we saw one or two microbursts which were classified as dry. It's certainly not enough to draw any conclusions about correlation of strength width, essentially we saw none in the southeast, and as we go to other parts of the country, Kansas City and wherever we go from there, that's certainly a study that we're interested in but the extent that we've seen low reflectivity microbursts, I'm not aware of anyone who's been able to see the slightest hint of correlation between their strength and their intensity in reflectivity research.

There were some questions that didn't get typed up, which I perhaps can try and go through very quickly. The first question is what kind of false alarm break do you feel to be expected for the 6 minute precursor alarm. A: That's an area that hasn't been looked at very carefully. What we do know is that when we see precursors we see them several minutes in advance of surface outflow. In terms of taking a setting and saying, how often do you see these same precursors and you've not seen microbursts. I'd say that's something we haven't looked at very carefully and certainly the false alarm rate there is the big thing to be concerned about and I'm afraid I'd be loafed to judge any kind of statistic to that, that's something that we're just beginning to look at.

Second is, "what's your opinion about how good the truth is that you compare your microburst detected by TDWR?"

A: The answer to that is pretty good. In most of these cases, as I mentioned, a tremendous amount of effort has gone into the development of this ground truth data base and for several years, we've been going though the processes of developing single doppler ground truth, that is where experienced people, I mean these are people who have been doing this for several years, look at the same radar data that's used by the algorithms, trying to identify where microbursts exist. That's an intermittent process that get's looked at several times, it gets refined and corrected. The process that people from NCAR are now involved with is looking at dual doppler information, trying to identify ground truth, it's a good deal more objective and should result in even higher quality ground truth. Assuring quality of that data is something, and as I mentioned put a very high priority on it and we have a lot of confidence in it. Third question is are there precursor programs available to be shared with this community? Yes, in a sense that these algorithms are documented and in fact, part of the Terminal Doppler Weather Radar System Specification. In fact, that's another part of the program which has taken up a lot of the effort: formally documenting these

algorithms so that they can be implemented by the system contractors. The actual software implementations that we use to compute these in the test bed, are in a sense, available in that it would certainly be possible to make arrangements to use those if there was someone who was really interested in that. The last question is, do you have additional source field of reflectivity to improve microburst simulation models? I'm not sure exactly what that means. One of the difficulties we have is .. excuse me, I think the question he was asking to model the dust and other things that are in the simulation other than moisture, didn't he mention dust and something else in there .. yes, if additional source field of reflectivity dust and bugs .. I think that he meant to add to the reflectivity information the backscatter levels from bugs and dust. If the question is, "if we try to figure out what contribution those sources would make towards reflectivity," the answer is no.

I would like to add that those questions were submitted by Cliff Schroeder of NASA Langley and he gave them to me, Bracalente of NASA, so that it gets into the record.

I didn't speak until I had the microphone. Spady is training me. Wayne Sand had a number of questions but he had fixed outbound. He will get in touch with the people personally and then give us copies of the answers. Our last set of questions is from Mssr. Bonnefay and then we will close.

I have two questions, one /?/ one /?/. Can I start by the /?/. Mr. Bonnefay, that's me. Is a copy of your presentation available? Yes, it is. I gave a copy to Herb Schlickermaier yesterday and in this paper, there is not only a presentation of the guidance but of the wind shear warning and also on wind shear guidance. The second question, the /?/ one is that one from Mr. Gaines, that's interesting. The direction change is not really apparent, what is the source of the wind shear warning. I thank

you for that question because I consider that it was not at all apparent I switched from the wind shear warning itself due to the time schedule but I can show you a viewgraph .. lights out .. this is the principal wind shear warning computation. It's not a warning taking into account separating factual or how is that a factor. It's a warning taking into account of the aircraft present energy from the angle of attack which is the best evaluation of your present energy taking into account sure of the setup and flaps position and considering the angle of attack would increase the angle of attack by several equivalent angle of attack estimated coming from the longitudinal wind derived source longitudinal shear from the memorized head wind increase before the shear appears it's a little bit predictive. Decreased by the min wind speed, equivalent angle of attack this is to decrease nuisance warning due to turbulence and wind creates also the general angle of attack by any equivalent angle of attack due to the vertical wind combining also those values we can have an efficient wind shear warning which is not related only to the wind itself. The main result in my finding is that we reach a very low level of nuisance warning compared to a simple measurement of the separating factor or the F factor, or the "SF" factor. You have here a comparison between a conventional wind shear warning nuisance performance warning and zero burst wind shear warning. We used for search and evaluation the AC 2057A wind model and we simulated more on the 500 simulation and on the left you have the level of warning appeared using a conventional system using F factor evaluation and on the right you have the nuisance warning level reached by the airbus wind shear warning. You can see on one side 10 to the minus 3 on the other side 10 to the minus 6. It was the goal which intended to reach because 10 to the minus 6 could be approximate activity, the wind shear and contour probability. But I can speak longer and longer on the warning, but see it fit here to stop.

Mr. Bonnefay, have you demonstrated that kind of nuisance performance? Have you demonstrated it for flight tests? I didn't mean you have to do 10 to 6 cycles .. A: I

don't have enough experience in flight for /?/ but I can confirm this result. Q: Does your early data suggest that you will meet that 10 to the minus 6? A: I hope it will meet but if I don't meet 10 to the minus 6 with such a device I wonder what would be the level of nuisance warning reached by the left system using just an F factor. It could be greater for airbus but it will be greater for the other. Something that is interesting considering just the AC 2057 A model because I reached using this model the nuisance warning of 10 to the minus 3. If I remember well, Roland, last year you demonstrate using a very different model or a very different way to the same level and if I remember also, in Boeing's studies we can consider that the possibility of reaching a level of 1.2 G is about 10 to the minus 3 also. So, if you are confident with the left part of this sheet I supposed that we have to also be confident with the right part of the sheet. Perhaps.

One other questions I would like to ask is have you made any comparison to your system with an F factor, for instance? Can you give us a comparison to the nuisance warning we can expect. A: I supposed the answer is in the attached sheet, but it's difficult to have a good wind and accurate wind modelization for a precise level of nuisance warning. So I consider the AC 2057 A wind model, why did I consider that model. It's just because we use it generally for landing or to landing the most efficient. It's not certain the very accurate rate model. It's not perhaps a very realistic model but it is a model and I can compare one system and also the system being a commonly agreed wind shear wind turbulence model. It's what we did and if FAA or NASA develop a new wind turbulence model it could be interesting to do exactly the same job using more realistic wind turbulence simulation in order to see if there is different level of wind shear warning and if we maintain the 10 to the minus 3 difference between an F factor system and an airbus wind shear warning system. We will do one in the future if the wind shear turbulence model is available.

Q: There's really no G threshold equivalent to your system? A: It could be, but look for /?/ equivalent, you must have a detection at .24 G, that's to say that when you detect it's really a little bit too late.

Q: Do you have equivalent data to this that shows the probability of a missed alert with the two different systems? A: About missed alert, I have no probability, what we demonstrate is that if we don't have an alert the plane can land safely or can go on the takeoff safely. All we detect and we have to oblige a normal procedure. Or we don't detect and we have to demonstrate that we can land safely or go on the takeoff safely but I don't know the possibility to reaching at deliver of those non-detection possibility of an opposite rating. Perhaps you have one.

Q: Maybe I should ask the question a different way? Do you have a feel for what the difference in relative timings of the alert are between the two system of how quickly your system will alert the time delay as compared to the conventional system? A: Yes, it's extremely difficult to report to answer that question due to fact that we consider the angle of attack, angle of attack represents the present situation of the plane and if you are in a very low energy situation, if you are flying at 1.3 V-Stall landing, you will have a very fast warning. It's about the same and sometimes quicker than the F system. If you are flying 1.5 V-Stall in that case the F system could warn earlier than airbus system, but if you are flying 1.4 or 1.5 V-Stall, you have a strong energy margin and you can wait for just a little while in order to prevent false warning or nuisance warning, so consider if your level of energy is slow because you fly 1.3 V-Stall or perhaps lower because there is an error, you will be warned very soon and if you have a very high level of energy, you will be warned later than the F system.

This is Howard Long with Delta. Does your system in any way provide you with a warning on a positive energy shear? A: No. Q: Have you made analysis of of that

as compared with the number of wind shears? A: We consider that it was not absolutely necessary because our plane, our protection devices outflow forward function, and your outflow forward function, already made protection, if we don't have the outflow forward function, certainly that we had implemented the alert on the increase inertia differ. But, due to the fact that it's perhaps not very good to increase the number of warnings in the cockpit, we prefer to develop only the red warning, taking into account there is a after /?/ protection with the outflow forward function. Q: If that information is available, don't you think it could be provided to the pilot? Q: If you've got the equipment on the airplane that's capable with providing the pilot with a positive shear data, that is, that you are in a significant increasing performance shear, shouldn't that information be available to pilots?

A: Yes, it is, considering the preliminary flight display where you have your speed scan, your speed also and you can compare your speed answer, nominal 1.3 with stall speed or 1.2 so, you know you are increasing strongly your speed and adjusting looking between your speed and your back speed exit. You have it all the time.

Q: Now did I understand from one slide that you already have this system certified? A: Yes, this system was certified last year for the A300 aircraft and certified as the A310 aircraft since April 1988 and it will be certified before the A310 next month and delivery at the beginning of 1989 and we intend to certify very similar system mainly for the warning for the 320 next year for delivery at the end of the year, something like that.

Just quickly, I might point out that the Boeing system is also being changed to account for higher energy levels above the 1.3 V-Stall. We agree, it's a good idea.

APPENDIXES

APPENDIX A

SECOND COMBINED MANUFACTURERS'

AND TECHNOLOGY AIRBORNE WIND

SHEAR REVIEW MEETING

-Agenda-

TUESDAY, 18 October 1988

7:45	Registration
8:45	Introduction of Guest Speaker
	Herbert Schlickenmaier, FAA
9:00	Welcome
	David Johnson, FAA
9:25	Logistics
	Amos Spady, NASA LaRC

SESSION I AIRBORNE - TERMS OF REFERENCE

9:30	Meeting Goals, Session Introduction
	Roland Bowles, NASA LaRC
9:45	Tools of the Trade
	Wally Gillman, American Airlines
10:05	SAE-S7 Wind Shear ARP
	Bob Ireland, United Airlines
10:25	Break
10:45	Wind Shear Regulatory Activities
	Steve Morrision, FAA
11:05	Flight Experience with Wind Shear Detection
	Terry Zweifiel, Honeywell/Sperry
11:25	Interface Standards for Integrated Predictive/Reactive WindShear Systems
	Mark McGlinchey, Honeywell/Sperry
11:45	Lunch

SESSION II   AIRBORNE - HAZARD DEFINITION

12:45   Session Introduction
         Amos Spady, NASA LaRC

12:50   Heavy Rain Effects on Airplane Performance
         Earl Dunham, NASA LaRC

1:10   Small Aircraft Performance in Wind Shear
         Dick Bray, NASA ARC

1:30   11 July, Weather and Resulting TDWR Alarms
         Wayne Sand, NCAR

1:50   Numerical Simulation of 11 July, Denver Microburst Storm
         Fred Procter, MESO

2:10   **Break**

2:30   11 July, Denver Wind Shear Encounters
         Bob Ireland, United Airlines

3:20   Questions and Answers for 18 October sessions

WEDNESDAY, 19 October 1988

8:00   Registration

SESSION I AIRBORNE - SENSORS

8:30   Session Introduction
            Roland Bowles, NASA LaRC

8:40   Wind Shear Radar Status Review and Introduction
            E. M. Bracalente, NASA LaRC

8:50   Analysis of Synthetic Aperture Radar (SAR) Data for Wind Shear Radar
            S. Harrah, NASA LaRC, V. Delnore, Kentron, and
            D. Gineris, ERIM

9:15   Preliminary Airborne Wind Shear Detection Radar Assessment Study
            C. L. Britt, RTI, and E. M. Bracalente, NASA LaRC

9:50   Clutter Filter Design Considerations for Airborne Wind Shear
            E. Baxa and A. Mackenzie, NASA LaRC

10:05   Airborne Radar Scatterometer Design & Flight Tests
            Bill Jones and Carrol Lytle, NASA LaRC

10:30   **Break**

10:45   Status of IR System Tests
            Pat Adamson, TPS

11:05   Status of Delco/Hughes IR Efforts
            Brian Gallagher, Delco/Hughes

11:25   IR Thermal Imaging of Atmospheric Turbulence
            Bill Pfeil, Kollsman

11:45   **Lunch**

12:45   Investigation of Airborne Lidar for Avoidance of Wind Shear Hazards
            Russell Targ, Lockheed

1:05   2.1 Micron Lidar Technology Program Status
            Mark Storm, NASA LaRC

SESSION II AIRBORNE - FLIGHT MANAGEMENT

1:25   Session Introduction
            Roland Bowles, NASA LaRC

1:40   Alert Filtering and Time Constants
            Kioumars Najmabadi, Boeing

2:00   Flight Guidance Research
             Dave Hinton, NASA LaRC

2:20   **Break**

2:40   Analysis of Guidance Law Performance Using PC Models
             Rene Barrios, Honeywell/Sperry

3:00   Flight Deck Research
             Dave Carbaugh, Boeing

3:20   An Expert System for Wind Shear Avoidance
             Robert Stengel, Princeton

3:40   Effect of Wind Shear During Takeoff Roll on Stopping Distance
             Terry Zweifiel, Honeywell/Sperry

4:00   Wind Shear Wind Model Simulator Analysis Status
             Bernard Ades, DGAC/SFACT/TV

4:15   Wind Shear Predictive Detector Technology Study Status
             C. Gandolfi, DGAC/STNA/3

4:30   Question and Answer Session for 19 October

THURSDAY, 20 October 1988

SESSION I GROUND SYSTEMS

8:30   Session Introduction
                Herbert Schlickenmaier, FAA

8:40   TDWR Program Status
                Art Hansen, FAA

9:00   LLWAS Program Status
                Craig Goff, FAA

9:20   1988 TDWR Operational Demonstration in Denver
                John McCarthy, NCAR

9:40   F-Factor Concept Applied to Surface Measurements
                Wayne Sand, NCAR

10:00   **Break**

10:20   Summer' 88 TDWR Microburst Analysis
                Mark Merritt, Lincoln Labs

10:40   Automatic Detection of Low Altitude Wind Shear Related Gust Fronts
                Diana Klinge-Wilson, Lincoln Labs

11:00   Sam Saint's Five Minutes
                Sam Saint, Safe Flight

11:20   Lessons Learned
                William Laynor, NTSB

11:40   **Lunch**

12:50   Introduction of Session
                Amos Spady, NASA LaRC

1:00   Ten Minute Presentations by those requesting time not available on the program schedule

2:00   Questions and Answers for all sessions

2:50   Closing Remarks
                Herbert Schlickenmaier, FAA
                Roland Bowles, NASA LaRC

3:00   **Conference Closed**

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18-20 OCTOBER 1988
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16. Abstract

The Second Combined Manufacturers' and Technologists' Conference was hosted jointly by NASA Langley (LaRC) and the Federal Aviation Administration (FAA) in Williamsburg, Virginia, on October 18-20, 1988. The meeting was co-chaired by Dr. Roland Bowles of LaRC and Herbert Schlickenmaier of the FAA. The purpose of the meeting was to transfer significant, ongoing results gained during the second year of the joint NASA/FAA Airborne Wind Shear Program to the technical industry and to pose problems of current concern to the combined group. It also provided a forum for manufacturers to review forward-look technology concepts and for technologists to gain an understanding of the problems encountered by the manufacturers during the development of airborne equipment and the FAA certification requirements. The present document has been compiled to record the essence of the technology updates and discussion which followed the session.

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